Humanized antibodies specific to the protofibrillar form of the beta-amyloid peptide

The present invention relates to humanized antibodies specific for the protofibrillar form of β-amyloid peptide. The present invention also relates to the therapeutic, diagnostic and/or preventive use of these antibodies, in particular associated with the induction and with the progression of neurodegenerative disorders and/or with diseases associated with the deposition of amyloid plaques, and notably Alzheimer's disease.

Alzheimer's disease (AD) is a progressive neurodegenerative disease that affects a high proportion of the older population. This disease is characterized clinically by memory loss and a decline in cognitive functions, and neuropathologically by the presence, in the brain, of intracellular neurofibrillar deposits and of extracellular deposits of the β-amyloid peptide (A-β) forming amyloid plaques. (Yanker et al. Nature Med. Vol. 2 No. 8 (1996)). As well as these signs, there are many other abnormal changes including a deterioration of the immune and inflammatory systems as well as a deterioration of mitochondrial function, which can lead to an increase in oxidative stress, activation of the mechanisms of apoptosis and ultimately to cell death.

Amyloid plaques are predominantly composed of A-β peptides with 40 or 42 residues, which are generated during the proteolytic process of the β-amyloid peptide precursor (APP) protein. The extracellular deposits of A-β peptides represent the invariable early characteristic feature of all forms of AD, including the familial forms (FAD). FADs appear relatively early (between 40 and 60 years) and are due to mutations in the gene of APP in 5% of cases of FAD (> 20 families) with six single or double missense mutations; in the gene of presenilin 1 (PS 1) in 50 to 70% of cases of FAD (> 200 families) with more than 80 different mutations identified to date; and in the gene of presenilin 2 (PS 2) in fewer cases of FAD with 2 missense mutations described in 8 families. Mutations in these three genes have been shown to induce changes in the proteolysis of APP, which lead to overproduction of A-β and to the early appearance of the pathology and of symptoms that are similar to those of the sporadic forms of AD.

The neuronal toxicity of the amyloid plaques might reside in the high molecular weight fibrils that are formed by aggregation of soluble A-β peptides in fibrillar forms that are soluble initially (also called protofibrillar form) and are then converted to insoluble

forms incorporated in the amyloid plaques. In fact, it was shown in vitro that the soluble A-β peptide aggregates progressively to a fibrillar form (i.e. which can be labelled with agents such as Congo Red or thioflavin S which recognize the beta-sheet tertiary structures of the peptides/proteins), of high molecular weight (>200 kDa) but still soluble. Because this form is soluble, it is often called the protofibrillar form, whereas the fibrils result from even greater aggregation, leading to loss of solubility. The protofibrillar transitional forms are generally regarded as the precursors of the amyloid fibres and might be responsible for the cellular dysfunction and the neuronal loss in Alzheimer's disease and in other diseases associated with the aggregation of proteins.

It has been shown that the senile amyloid plaques (i.e. aggregated, also called mature plaques) are correlated with the cognitive status of Alzheimer's patients in contrast to the diffuse deposits of A-β peptide which are also widely present in unaffected patients. (Duyckaerts et al., Neurobiol. Aging 1997; 18: 33-42 and Jellinger et al., 1998; 54:77-95). By targeting these senile amyloid plaques in particular, it is therefore possible to treat Alzheimer's disease more specifically and effectively.

A great many treatments have been tried for preventing the formation of the A-β peptides, for example inhibitors of the proteolytic process of APP.

Immunotherapeutic strategies such as the administration of anti-A-β antibody (to reduce the amyloid deposits) or immunization with antigens of the A-β peptides (to promote a humoral response) have been tested in order to reduce the size and density of the plaques.

For example, a method of treatment against Alzheimer's disease has been described (US 7 179 463), consisting of administering an antibody directed against a protofibril presenting an Arctic mutation in the region coding for the A-β peptide.

No example of antibody has really been described. Moreover, no comparison of the affinity of the antibodies for the peptides as a function of the molecular weight of these peptides has been performed. Other patents (US 6 761 888 and US 6 750 324) have referred to antibodies recognizing various epitopes along the amino acid sequence of the peptide A-β_{42}. An international application (WO2007/108756) has been filed concerning antibodies specific for the protofibrils but the antibodies described recognize both the high molecular weight A-β peptides and the medium-weight oligomers. Furthermore, there is no mention of the affinity of the antibodies for the mature plaques relative to their affinity for the diffuse plaques.

Despite the current development of knowledge concerning Alzheimer's disease, there is still a need for compositions and methods of treatment and/or prevention of this pathology limiting the secondary effects to the maximum extent. Antibodies such as described in the present application, humanized and specific for the protofibrillar form of the A-β peptides, aim to solve this problem. Permitting recognition of the senile amyloid plaques but not the diffuse plaques, the antibodies according to the invention recognize the pathological plaques much more effectively than antibodies recognizing all forms of Abeta, which will largely be attached to the diffuse deposits or attached to the soluble forms of monomeric or low-molecular-weight A-β peptide.

Moreover, the fact that only the protofibrillar forms of the A-β peptides are recognized and not the protofibrillar forms of other proteins not linked to Alzheimer's disease avoids useless binding that may reduce the concentration of antibodies that are effective against the disease.

The murine antibody that has been humanized will be called antibody 13C3 throughout the present application.

The sequences that can code for or constitute the humanized antibodies according to the invention are shown in Table 2.

The present invention relates to a humanized antibody that binds specifically to the protofibrillar form of the A-β peptide, i.e. a high molecular weight peptide.

In a more advantageous embodiment, the antibody binds to the A-β peptide having a molecular weight greater than 200, 300, 400 or 500 kDa.

According to one embodiment, the antibody according to the invention binds to the A-β peptides aggregated into senile plaques and not to the diffuse deposits of A-β peptides.

In an advantageous embodiment, the antibody according to the invention binds specifically to the protofibrillar form of the A-β peptide but not to the other proteins of amyloid structure (for example IAPP, Islet Amyloid Polypeptide).

The present invention also relates to a humanized antibody having reduced effector functions, making it possible to limit adverse effects such as the development of microhaemorrhages and vasogenic oedemas.

In an advantageous embodiment, the antibody according to the invention no longer possesses effector functions.

In an even more advantageous embodiment, the antibody is an immunoglobulin G 4 whose Fc domain has undergone mutations reducing the production of half-molecules.

In an even more advantageous embodiment, the antibody is an immunoglobulin G 4 whose Fc domain has undergone mutations reducing the effector activity.

The present invention relates to a humanized antibody comprising at least one CDR encoded by a nucleotide sequence having a sequence identical to one of the sequences SEQ ID NO: 9, 11, 13, 15, 17 and 19, or by sequences differing respectively by 1, 2, 3, 4 or 5 nucleotides from these sequences.

The present invention also relates to a humanized antibody comprising at least one CDR having a sequence identical to one of the sequences SEQ ID NO: 10, 12, 14, 16, 18 and 20.

In another embodiment, the antibody according to the invention comprises at least one CDR whose sequence differs by one to two amino acids relative to one of the sequences SEQ ID NO: 10, 12, 14, 16, 18, 20 and 32, inasmuch as the antibody maintains its binding specificity.

In an advantageous embodiment, the antibody comprises the CDRs encoded by the nucleotide sequences SEQ ID NO: 9, 11, 13, 15, 17 and 19, or by sequences differing respectively by 1, 2, 3, 4 or 5 nucleotides from these sequences.

In another advantageous embodiment, the antibody comprises the CDRs of sequence SEQ ID NO: 10, 12, 14, 16, 18 and 20.

The antibody according to the invention can also comprise the CDRs encoded by the nucleotide sequences SEQ ID NO: 9, 11, 13, 31, 17 and 19 or by sequences differing respectively by 1, 2, 3, 4 or 5 nucleotides from these sequences.

In an advantageous embodiment, the antibody according to the invention comprises the CDRs of sequence SEQ ID NO: 10, 12, 14, 32, 18 and 20.

One object of the invention is the humanized antibody comprising the CDRs encoded by the nucleotide sequences SEQ ID NO: 9, 11, 29, 31, 17 and 19 or by sequences differing respectively by 1, 2, 3, 4 or 5 nucleotides from these sequences.

The invention also relates to a humanized antibody comprising the CDRs of sequence SEQ ID NO: 10, 12, 30, 32, 18 and 20.

In an advantageous embodiment, the antibody according to the invention comprises a variable part of its heavy chain (VH) encoded by a sequence having at least 80%, 85%, 90%, 95% or 99% identity with the sequence SEQ ID NO: 5 or the sequence SEQ ID NO 27.

In an advantageous embodiment, the antibody according to the invention comprises a variable part of its heavy chain (VH) comprising a sequence having at least 80%, 85%, 90%, 95% or 99% identity with the sequence SEQ ID NO: 6 or the sequence SEQ ID NO 28.

In an advantageous embodiment, the antibody according to the invention comprises a variable part of its light chain (VL) encoded by a sequence having at least 80%, 85%, 90%, 95% or 99% identity with the sequence SEQ ID NO: 7 or the sequence SEQ ID NO 23.

In an advantageous embodiment, the antibody according to the invention comprises a variable part of its light chain (VL) comprising a sequence having at least 80%, 85%, 90%, 95% or 99% identity with the sequence SEQ ID NO: 8 or the sequence SEQ ID NO 24.

In an even more advantageous embodiment, the antibody comprises a heavy chain comprising a variable part (VH) encoded by one of the nucleotide sequences SEQ ID NO 5 and SEQ ID NO 27.

In an even more advantageous embodiment, the antibody comprises a heavy chain comprising a variable part (VH) of polypeptide sequence SEQ ID NO 6 or SEQ ID NO 28.

In another embodiment, the antibody comprises a light chain comprising a variable part (VL) encoded by one of the nucleotide sequences SEQ ID NO 7 and SEQ ID NO 23.

In another embodiment, the antibody comprises a light chain comprising a variable

part (VL) of polypeptide sequence SEQ ID NO 8 or SEQ ID NO 24.

In an advantageous embodiment, the antibody comprises the sequences encoded by the nucleotide sequences SEQ ID NO: 5 and 7.

In an advantageous embodiment, the antibody comprises the polypeptide sequences SEQ ID NO: 6 and 8.

In another embodiment, the antibody comprises the sequences encoded by the nucleotide sequences SEQ ID NO: 5 and 23.

In another embodiment, the antibody comprises the polypeptide sequences SEQ ID NO: 6 and 24.

In another embodiment, the antibody comprises the sequences encoded by the nucleotide sequences SEQ ID NO: 27 and 23.

In another embodiment, the antibody comprises the polypeptide sequences SEQ ID NO: 28 and 24.

The present invention also relates to an antibody comprising a heavy chain encoded by a sequence having at least 80%, 85%, 90%, 95% or 99% identity with one of the nucleotide sequences SEQ ID NO 1 and SEQ ID NO 25.

The present invention also relates to an antibody comprising a heavy chain having at least 80%, 85%, 90%, 95% or 99% identity with the polypeptide sequence SEQ ID NO 2 or with the polypeptide sequence SEQ ID NO 26.

In an advantageous embodiment the antibody comprises a light chain encoded by a sequence having at least 80%, 85%, 90%, 95% or 99% identity with one of the nucleotide sequences SEQ ID NO 3 and SEQ ID NO 21.

In another embodiment the antibody comprises a light chain comprising a sequence having at least 80%, 85%, 90%, 95% or 99% identity with one of the polypeptide sequences SEQ ID NO 4 and SEQ ID NO 22.

One object of the invention is an antibody comprising the sequences encoded by the nucleotide sequences SEQ ID NO: 1 and 3.

Another object of the invention is an antibody whose sequence comprises the polypeptide sequences SEQ ID NO: 2 and 4.

One object of the invention is an antibody comprising the sequences encoded by the nucleotide sequences SEQ ID NO: 1 and 21.
Another object of the invention is an antibody whose sequence comprises the polypeptide sequences SEQ ID NO: 2 and 22.

One object of the invention is an antibody comprising the sequences encoded by the nucleotide sequences SEQ ID NO: 25 and 21.
Another object of the invention is an antibody whose sequence comprises the polypeptide sequences SEQ ID NO: 26 and 22.

Another object of the invention is a humanized anti-peptide Aβ antibody having an affinity for the protofibrillar form of peptide Aβ at least 100 times greater than its affinity for the other forms of this peptide.
Another object of the invention is an antibody, characterized in that it induces a reduction of amyloid plaques.

Another object of the invention is the use of a humanized anti-peptide Aβ antibody in the treatment of diseases associated with neurodegenerative disorders, and in particular in the treatment of Alzheimer's disease.
Another object of the invention is a pharmaceutical composition comprising a humanized anti-peptide Aβ antibody and excipients.
Another object of the invention is a method of treatment of Alzheimer's disease comprising the administration of a humanized anti-peptide-Aβ antibody to the patient.

Another object of the invention is a cell or cells producing a humanized anti-peptide-Aβ antibody, as well as the method of production of this antibody comprising the culturing of these cells. Said cells are derived advantageously from one cell line.

One object of the invention is a medicinal product comprising a humanized anti-peptide-Aβ antibody.

One object of the invention is a polynucleotide coding for a polypeptide having at least 80%, 85%, 90%, 95% or 99% identity with one of the sequences SEQ ID NO: 2, 4, 6, 8, 22, 24, 26 or 28.

Another object of the invention is a polynucleotide with a sequence having at least 80%, 85%, 90%, 95% or 99% identity with one of the sequences SEQ ID NO: 1, 3, 5, 7, 21, 23, 25, or 27.

Another object of the invention is a recombinant vector comprising a nucleic acid having one of the sequences SEQ ID NO 1, 3, 5, 7, 21, 23, 25, or 27, as well as a host cell comprising this vector.

Definitions

Specific binding is understood as a difference by a factor of at least about 10, 20, 30, 40, 50, or 100 between the strength of binding to one receptor relative to another, here between binding to the protofibrillar form of the A-β peptide and binding to the other forms of the peptide.

"Epitope" means the site of the antigen to which the antibody binds. If the antigen is a polymer, such as a protein or a polysaccharide, the epitope can be formed by contiguous or non-contiguous residues. Here the epitope is conformational, i.e. related to the three-dimensional structure of the protofibrillar A-β peptide.

"Protofibrillar form" means an oligomeric form of A-β peptides, soluble in vitro and which can be isolated as an entity of molecular weight greater than 200 kDa, 300 kDa, 400 kDa or 500 kDa and which can fix agents such as thioflavin-S or Congo Red.

"Senile plaque" means a plaque composed of an amyloid core (fixing thioflavin S or Congo Red) surrounded by dystrophic neurites and a reaction of glial cells. Senile plaques are found in particular in patients with Alzheimer's disease, in contrast to the diffuse amyloid deposits (which do not fix thioflavin S or Congo Red), which are far more numerous but are not associated with the disease.

An antibody, also called immunoglobulin, is composed of two identical heavy chains ("CH") and two identical light chains ("CL"), which are joined by a disulphide bridge.

Each chain contains a constant region and a variable region. Each variable region comprises three segments called "complementarity determining regions" ("CDRs") or "hypervariable regions", which are mainly responsible for binding to the epitope of an antigen.

The term "VH" refers to the variable regions of a heavy chain of immunoglobulin of an antibody, including the heavy chains of a fragment Fv, scFv, dsFv, Fab, Fab' or F(ab)'.

The term "VL" refers to the variable regions of a light chain of immunoglobulin of an antibody, including the light chains of a fragment Fv, scFv, dsFv, Fab, Fab' or F(ab)'.

"Antibody" also means any functional fragment of antibody: Fab (Fragment antigen binding), Fv, scFv (single chain Fv), Fc (Fragment, crystallizable). Preferably, these functional fragments will be fragments of type Fv, scFv, Fab, F(ab') 2, Fab', scFv-Fc, diabodies, multispecific antibodies (notably bispecific), synthetic polypeptides containing the sequences of one or more CDRs, which generally possess the same specificity of fixation as the humanized antibody from which they are derived. According to the present invention, fragments of antibodies of the invention can be obtained from the humanized antibodies by methods such as digestion by enzymes, such as pepsin or papain and/or by cleavage of the disulphide bridges by chemical reduction.
Nanobodies also come under this definition.

"CDR or CDRs" denotes the hypervariable regions of the heavy and light chains of the immunoglobulins as defined by Kabat et al. (Kabat et al., Sequences of proteins of immunological interest, 5th Ed., U.S. Department of Health and Human Services, NIH, 1991, and later editions). There are 3 heavy-chain CDRs and 3 light-chain CDRs. The term CDR or CDRs is used here to denote, as applicable, one or more, or even all, of these regions that contain the majority of the amino acid residues responsible for the affine binding of the antibody for the antigen or the epitope that it recognizes. The most conserved regions of the variable domains are called FR regions or sequences, for "framework regions".

The present invention relates to humanized antibodies.

"Humanized antibody" means an antibody that contains mainly human immunoglobulin sequences. This term generally refers to a non-human immunoglobulin that has been modified by incorporating human sequences or residues found in human sequences.

In general, humanized antibodies comprise one or typically two variable domains in which all or part of the CDR regions correspond to parts derived from the non-human parent sequence and in which all or part of the FR regions are derived from a human immunoglobulin sequence. The humanized antibody can then comprise at least one portion of a constant region of immunoglobulin (Fc), in particular that of the selected reference human immunoglobulin.
We thus try to obtain an antibody that is the least immunogenic in a human. Thus it is possible that one or two amino acids of one or more CDRs are modified by an amino acid that is less immunogenic for the human host, without substantially reducing the binding specificity of the antibody to the A-β peptide of high molecular weight. Furthermore, the residues of the framework regions need not be human and it is possible that they are not modified, as they do not contribute to the immunogenic potential of the antibody.

Several methods of humanization are known by a person skilled in the art for modifying a non-human parent antibody to an antibody that is less immunogenic in humans. Complete identity of the sequences with a human antibody is not essential. In fact complete sequence identity is not necessarily a predictive indicator of reduced immunogenicity and modification of a limited number of residues can lead to humanized antibodies presenting a very attenuated immunogenic potential in humans (Molecular Immunology (2007) 44, 1986-1998).

Some methods are for example the inclusion of CDRs (grafting) (EPO 0 239 400; WO 91/09967; and U.S. Pat. Nos. 5,530,101 and 5,585,089), the resurfacing (EPO 0 592 106; EPO 0 519 596; Padlan, 1991, Molec Imm 28(4/5):489-498; Studnicka et al., 1994, Prot Eng 7(6):805-814; and Roguska et al., 1994, PNAS 91:969-973) or chain mixing (U.S. Pat. No. 5,565,332).

The present invention relates in particular to humanized antibodies whose variable parts are modified according to the technology explained in international patent application WO 2009/032661.
This technique notably uses dynamic molecular simulation based on three-dimensional models of antibodies, said models being constructed by homology.

The present invention also relates to any form of antibody having diminished effector functions, such as immunoglobulins bearing mutations of the Fc domain reducing its affinity for the receptors of the immune system or such as nanobodies.

"Effector functions" means any fixation of the Fc domain of the antibody to receptors or proteins inducing immune responses. Decreasing these effector functions makes it possible to reduce adverse effects such as the induction of microhaemorrhages (Racke et al. J Neurosci 2005, 25:629).

Affinity can be measured by any technique known by a person skilled in the art. It is advantageously measured by the Biostat Speed technique developed on the basis of the algorithms described by Ratkovsk DA and Reedy TJ (Biometrics, 1986, 42, 575-82).

In order to permit expression of heavy chains and/or light chains of the antibody according to the invention, the polynucleotides coding for said chains are inserted in expression vectors. These expression vectors can be plasmids, YACs, cosmids, retroviruses, episomes derived from EBV, and all the vectors that a person skilled in the art may judge to be suitable for expression of said chains.

These vectors can be used for transforming cells advantageously derived from one cell line. Said cell line is even more advantageously derived from a mammal.
It is advantageously the CHO line or a line derived from this line, or the HEK293 line or a line derived from this line.

The transformation of the cells can be carried out by any method known by a person skilled in the art for introducing polynucleotides into a host cell. Said method can be transformation by means of dextran, precipitation by calcium phosphate, transfection

by means of polybrene, protoplast fusion, electroporation, encapsulation of the polynucleotides in liposomes, biolistic injection and direct micro-injection of DNA into the nucleus.

The antibody according to the invention can be included in pharmaceutical compositions with a view to administration by the topical, oral, parenteral, intranasal, intravenous, intramuscular, subcutaneous, intraocular or other routes. Preferably, the pharmaceutical compositions contain pharmaceutically acceptable vehicles for an injectable formulation. These can be in particular sterile, isotonic saline solutions (monosodium or disodium phosphate, sodium, potassium, calcium or magnesium chloride, etc., or mixtures of said salts), or dry compositions, notably lyophilized, which, by adding sterilized water or physiological serum as appropriate, permit injectable solutes to be constituted.

As an example, a pharmaceutical composition comprises (1) a Dulbecco phosphate buffer (pH ~ 7.4), optionally containing 1 mg/ml to 25 mg/ml of human serum albumin, (2) 0.9% w/v of sodium chloride (NaCl), and (3) 5% (w/v) of dextrose. It can also comprise an antioxidant such as tryptamine and a stabilizer such as Tween 20.

The pathologies in question can be any diseases associated with the deposition of amyloid plaques. In particular, the pathology in question is Alzheimer's disease.

The doses depend on the desired effect, the duration of the treatment and the route of administration used; they are generally between 5 mg and 1000 mg of antibody per day for an adult. Generally the doctor will determine the appropriate dosage in relation to the stage of the disease, the patient's age and weight, or any other patient-related factor that has to be taken into account.

The present invention is illustrated, but is not limited, by the examples given below.

Brief description of the drawings:

Fig. 1A: Map of the plasmid pXL4973 permitting expression of the light chain LC1 of the antiAbeta antibody 13C3-VH1VL1.

Fig. 1B: Map of the plasmid pXL4979 permitting expression of the heavy chain HC1 of the antiAbeta antibody 13C3-VH1VL1.

Fig. 2A and 2B: Separation of the protofibrils and of the low-molecular-weight oligomers by gel filtration on Superdex 75 (at t=0 and at t=16h respectively).

Fig. 3: Determination of the molecular weight of the protofibrils.

Fig. 4A, 4B and 4C: Determination of the affinities of the humanized antibodies (antibodies LP09027 (4A), LP09026 (4B) and LP09028 (4C) respectively) for the protofibrils (mean value from 3 experiments ± sem).

Fig. 5: Specificity of the humanized antibody LP09027 with respect to fibrils of Aβ.

Fig. 6A and 6B: Specificity of the humanized antibody (LP09027) for the mature senile plaques respectively of the frontal cortex (6A) and of the hippocampus (6B) of a mouse. The arrows indicate the senile plaques.

EXAMPLES:

Example 1: Obtaining humanized antibodies

A murine antibody 13C3 was humanized.

This example describes the sequence and the production of the humanized anti-peptide Aβ antibody VH1VL1 (LP09027) by production by transient expression in the mammalian line HEK293 designated FreeStyle 293-F.

The cDNAs coding for the humanized variable chains VL1 and VH1 are fused with the cDNAs coding for the human constant regions Ckappa and IgG4 respectively. The sequence of the constant region IgG4 is that of the variant having the substitutions S241P and L248E in Kabat's nomenclature, for a significant reduction in the production of half-molecules (Angla et al., 1993, *Mol. Immunol.*, 30: 105-108) and the effector functions (WO 97/09351).

The nucleic acid sequences coding for CH1 (SEQ ID NO 1) and for CL1 (SEQ ID NO 3) were cloned independently in the expression vector to generate the plasmids pXL4973 (Fig. 1A) and pXL4979 (Fig. 1B), respectively.

A batch of the antibody is produced by production by transient expression in the line FreeStyle 293-F (Invitrogen) after co-transfection of the plasmids pXL4973 and pXL4979 according to the protocol described by Invitrogen (catalogue reference K9000-01). This batch (LP09027) is then purified by affinity chromatography on a column of MabSelect gel (Amersham) according to the supplier's recommendations and then formulated in PBS buffer (reference Dulbecco 14190-094) and submitted to sterile filtration (0.2 µm). Starting from 1 L of culture, 33 mg of antibody is obtained at a purity of 97% by SDS-PAGE in denaturing conditions and by steric exclusion chromatography. The mass obtained by SDS-PAGE in denaturing conditions and by LC/MS is in agreement with the primary amino acid sequence and the presence of an N-glycan on the Fc domain, namely a mass of 23969 Da for LC1 and 49650 Da for HC1 taking into account the N-glycan in the G0F form. The mass obtained by SDS-PAGE in non-denaturing conditions and by size exclusion chromatography is in agreement with the hetero-tetrameric structure of the antibody of 150 kDa (Fig. 4A).

According to the same method, batches of humanized antibodies LP09026 and LP09028 were produced starting from the nucleotide sequences SEQ ID NO 25 and SEQ ID NO 21 for LP09026 (Fig. 4B), and SEQ ID NO 1 and SEQ ID NO 21 for LP09028 (Fig. 4C).

Example 2: Preparation of protofibrils from peptide Aβ (1-42)

The protofibrils were prepared from the synthetic peptide Aβ (1-42) according to the method described by Johansson et al. (FEBS, 2006, 2618-2630). The lyophilized peptide (Anaspec reference 24224) is dissolved in 10 mM NaOH at a concentration of 100µM, then stirred for 1 min and incubated on ice for 10 min. The solution of peptide is then diluted in buffer of 100 mM sodium phosphate, 200 mM NaCl pH=7.4 to a concentration of 50 µM, then stirred for 1 min. The preparation is incubated overnight at 37°C for formation of protofibrils and then centrifuged at 17900g for 15 min at 16°C to remove the insoluble aggregates. To separate the protofibrils from the oligomeric forms of Aβ of low molecular weight, the supernatant is loaded on a Superdex 75 gel filtration column equilibrated in 50 mM ammonium acetate buffer pH=8.5. The

fractions corresponding to the protofibrils and to the low-molecular-weight oligomers are collected and stored at 4°C. Fig. 2 shows a typical profile of separation of the protofibrils. The molecular weight of the protofibrils is determined by Superdex200 gel filtration using, as markers of molecular weight, the Biorad calibration kit (reference 150-1901). Fig. 3 shows that the molecular weight of the protofibrils is greater than 200 kDa.

Example 3: Specificity and affinity of the humanized antibodies with respect to the protofibrils

50µl of protofibrils and low-molecular-weight oligomers at a concentration of 1 µg/ml in PBS (Gibco, reference 70011) are deposited in the wells of an ELISA plate (Nunc, reference 442404) and incubated overnight at 4°C. After removing the excess antigen, 200 µl of buffer PBS + 5% milk powder (weight/volume) is deposited in each well to remove the non-specific adsorptions and incubated for 2h at room temperature. The wells are then washed 4 times with 300 µl of buffer PBS Tween 0.02%. 50 µl of a primary antibody solution (dilution of 3 in 3 in PBS Tween starting from a concentration of 100µg/ml for the oligomers and from 25 µg/ml for the protofibrils) is added to each well and incubated for 1h at room temperature. The wells are washed 4 times with 300µl of buffer PBS Tween. The secondary anti-Fc human antibody coupled to peroxidase (Goat Anti Human IgG (Fc) peroxidase conjugated, Pierce, reference 31413) diluted to 1/10000 in buffer PBS Tween is added to each well and incubated for 1 h at room temperature. After 4 washings with 300 µl of PBS Tween, 100 µl of TMB (Interchim, reference UP664782) is added to each well and incubated for about 10 min, then the reaction is stopped with a solution of 1M HCl (Interchim, reference UPS29590) and the plates are read at an OD measured at a wavelength of 450nm. The EC50 values are determined by BioStat Speed. The results obtained are presented in Table 1 and in Fig. 4 and show the very high specificity of the antibody for the protofibrils relative to the low-molecular-weight oligomers (factor of 184).

Table 1:

EC50 (µg/ml)	LMW	PF	LMW/PF
LP09026	41.4 ± 40.1	0.0587 ± 0.004	705.3
LP09027	14.7 ± 2.7	0.0798 ± 0.007	184.2
LP09028	21.8 ± 5.3	0.0892 ± 0.007	244.4

The lyophilized peptide Aβ1-42 (Anaspec reference 24224) is dissolved according to the supplier's recommendations: 40 µl of 1% NH4OH is added to 500 µg of Aβ1-42. After complete dissolution, 460 µl of PBS is added to obtain a concentration of 1 mg/ml. Aliquots of 10 µl are prepared and stored at -80°C.

50µl of a solution of peptide Aβ1-42 at a concentration of 1 µg/ml in carbonate buffer ($NaHCO_3$ 0.025 M (Acros Organics, reference 217120010), Na_2CO_3 0.025 M (Acros Organics, reference 207810010), pH 9.7 is deposited in the wells of an ELISA plate and incubated overnight at room temperature. As previously, the wells are washed with buffer PBS Tween, incubated in the presence of buffer PBS + 5% milk powder (weight/volume) and washed with buffer PBS Tween. The humanized antibody at a concentration of 0.02 µg/ml is incubated for 1h at room temperature with a concentration range (starting from 1 µg/ml) of peptides Aβ1-28 (Bachem, reference H7865), Aβ1-16 (Anaspec, reference 24225), Aβ25-35 (Anaspec, reference 24227), low-molecular-weight oligomers or protofibrils prepared as described previously. The antibody/antigen mixture is then deposited in each well and the microtitration plate is incubated for 1h at room temperature. The free, uncomplexed antibody is determined according to the same ELISA protocol as described previously. These competitive experiments show that only the protofibrils with a much higher affinity than the low-molecular-weight oligomers are capable of neutralizing the humanized antibody by preventing it from interacting with the peptide Aβ1-42; none of the peptides is capable of neutralizing the antibody.

Example 4: Specificity of the humanized antibody LP09027 with respect to the fibrils of Aβ1-42

The peptide Aβ1-42 (Anaspec, 20276) is dissolved in 200 µl of 10 mM NaOH to a concentration of 5 mg/ml. The peptide IAPP (Anaspec, 60804) is diluted in 200 µl of 50% DMSO to a concentration of 5 mg/ml. 100 µl of each preparation is diluted in 400 µl of PBS 1.25X. The final concentration of the peptides is 1 mg/ml in 500 µl. The samples are incubated for 72h at 37°C. After incubation, the samples are centrifuged at 17900g for 30 minutes at 4°C. The supernatant is removed and the pellet is washed 3 times with PBS 1X. After the last washing, the pellet of fibrils is taken up in 150 µl of PBS. To check for the presence of fibrils of amyloid type, a thioflavin T fluorescence test (Anaspec, 88306) is carried out. 20 µl of thioflavin T (20 µM final), 10 µl of the sample and 70 µl of PBS 1X (final volume 100 µl) are mixed in a well of a black plate (Corning, 3792). The thioflavin T is excited at 450 nm and, in the presence of a structure of amyloid type, emits fluorescence at 482 nm. 50 µl of fibrils of Aβ1-42 at 1 µg/ml and IAPP at 0.5 µg/ml are deposited in each well of a microtitration plate. The ELISA protocol is applied using serial dilutions of the humanized antibody starting from 10 µg/ml. Fig. 5 shows that the humanized antibody LP09027 specifically recognizes the fibrils of Aβ1-42 but not those of IAPP.

Example 5: Specificity of the humanized antibody LP09027 for the mature senile plaques but not for the diffuse plaques

The humanized antibody (LP09027) conjugated with digoxigenin (digoxigenin-3-O-methylcarbonyl-ε-aminocaproic acid-N-hydroxysuccinimide ester: Roche 11333054001; 11418165001) was used in immunohistochemistry (Ventana Robot) on brain sections from mice APP PS1 (Alzheimer model described by Schmitz C. et al., Am. J. Pathol, 2004, 164, 1495-1502) as well as human brain sections (cerebral cortex) derived from patients with Alzheimer's disease. The samples had been fixed in formol and embedded in paraffin beforehand.

The results obtained in the mouse (Figs. 6A and 6B) clearly show that the humanized antibody recognizes exclusively the dense, mature senile plaques, but not the diffuse deposits of peptide Aβ.

These data correlate with the properties of this antibody, which is specific for the protofibrillar Abeta form and so does not recognize the soluble, mono- or oligomeric forms of this peptide.

Table 2:

	Nucleotide sequences	Protein sequences
Antibody 1 VH1VL1		
$VH_1 + CH_1$	SEQ ID NO 1	SEQ ID NO 2
$VL_1 + CL_1$	SEQ ID NO 3	SEQ ID NO 4
VH_1	SEQ ID NO 5	SEQ ID NO 6
VL_1	SEQ ID NO 7	SEQ ID NO 8
CDR VH_1	SEQ ID NO 9, 11, 13	SEQ ID NO 10, 12, 14
CDR VL_1	SEQ ID NO 15, 17, 19	SEQ ID NO 16, 18, 20
Antibody 2 VH1 VL2		
$VH_1 + CH_1$	SEQ ID NO 1	SEQ ID NO 2
$VL_2 + CL_2$	SEQ ID NO 21	SEQ ID NO 22
VH_1	SEQ ID NO 5	SEQ ID NO 6
VL_2	SEQ ID NO 23	SEQ ID NO 24
CDR VH_1	SEQ ID NO 9, 11, 13	SEQ ID NO 10, 12, 14
CDR VL_2	SEQ ID NO 31, 17, 19	SEQ ID NO 32, 18, 20
Antibody 3 VH2 VL2		
$VH_2 + CH_2$	SEQ ID NO 25	SEQ ID NO 26
$VL_2 + CL_2$	SEQ ID NO 21	SEQ ID NO 22
VH_2	SEQ ID NO 27	SEQ ID NO 28
VL2	SEQ ID NO 23	SEQ ID NO 24
CDR VH_2	SEQ ID NO 9, 11, 29	SEQ ID NO 10, 12, 30
CDR VL_2	SEQ ID NO 31, 17, 19	SEQ ID NO 32, 18, 20

Claims

1. Humanized antibody specific for the protofibrillar form of the A-β peptide.

2. Antibody according to Claim 1, characterized in that it binds to the A-β peptides aggregated in senile plaques and not to the diffuse deposits of A-β peptides.

3. Antibody according to one of the preceding claims, characterized in that it comprises at least one CDR encoded by a nucleotide sequence having a sequence identical to one of the sequences SEQ ID NO: 9, 11, 13, 15, 17 and 19, or by sequences differing respectively by 1, 2, 3, 4 or 5 nucleotides from these sequences.

4. Antibody according to one of the preceding claims, characterized in that it comprises at least one CDR having a sequence identical to one of the sequences SEQ ID NO: 10, 12, 14, 16, 18 and 20.

5. Antibody according to one of the preceding claims, characterized in that it comprises at least one CDR whose sequence differs by one to two amino acids relative to one of the sequences SEQ ID NO: 10, 12, 14, 16, 18 and 20, inasmuch as the antibody maintains its binding specificity.

6. Antibody according to one of the preceding claims, characterized in that it comprises the CDRs encoded by the nucleotide sequences SEQ ID NO 9, 11, 13, 15, 17 and 19, or by sequences differing respectively by 1, 2, 3, 4 or 5 nucleotides from these sequences.

7. Antibody according to one of the preceding claims, characterized in that it comprises the CDRs of sequence SEQ ID NO: 10, 12, 14, 16, 18 and 20.

8. Antibody according to one of the preceding claims, characterized in that it comprises the CDRs encoded by the nucleotide sequences SEQ ID NO 9, 11,

13, 31, 17 and 19, or by sequences differing respectively by 1, 2, 3, 4 or 5 nucleotides from these sequences.

9. Antibody according to one of the preceding claims, characterized in that it comprises the CDRs of sequence SEQ ID NO: 10, 12, 14, 32, 18 and 20.

10. Antibody according to one of the preceding claims, characterized in that it comprises the CDRs encoded by the nucleotide sequences SEQ ID NO 9, 11, 29, 31, 17 and 19, or by sequences differing respectively by 1, 2, 3, 4 or 5 nucleotides from these sequences.

11. Antibody according to one of the preceding claims, characterized in that it comprises the CDRs of sequence SEQ ID NO: 10, 12, 30, 32, 18 and 20.

12. Antibody according to one of the preceding claims, characterized in that the variable part of its heavy chain is encoded by a sequence having at least 80% identity with one of the sequences SEQ ID NO: 5 and SEQ ID NO 27.

13. Antibody according to one of the preceding claims, characterized in that the variable part of its heavy chain comprises a sequence having at least 80% identity with one of the sequences SEQ ID NO: 6 and SEQ ID NO 28.

14. Antibody according to one of the preceding claims, characterized in that the variable part of its light chain is encoded by a sequence having at least 80% identity with one of the sequences SEQ ID NO: 7 and SEQ ID NO 23.

15. Antibody according to one of the preceding claims, characterized in that the variable part of its light chain comprises a sequence having at least 80% identity with one of the sequences SEQ ID NO: 8 and SEQ ID NO 24.

16. Antibody according to one of the preceding claims, characterized in that it comprises a heavy chain comprising a variable part encoded by one of the nucleotide sequences SEQ ID NO 5 and SEQ ID NO 27.

17. Antibody according to one of the preceding claims, characterized in that it comprises a heavy chain comprising a variable part of polypeptide sequence SEQ ID NO 6 or SEQ ID NO 28.

18. Antibody according to one of the preceding claims, characterized in that it comprises a light chain comprising a variable part encoded by one of the nucleotide sequences SEQ ID NO 7 and SEQ ID NO 23.

19. Antibody according to one of the preceding claims, characterized in that it comprises a light chain comprising a variable part of polypeptide sequence SEQ ID NO 8 or SEQ ID NO 24.

20. Antibody according to one of the preceding claims, characterized in that it comprises sequences encoded by the nucleotide sequences SEQ ID NO: 5 and 7.

21. Antibody according to one of the preceding claims, characterized in that its sequence comprises the polypeptide sequences SEQ ID NO: 6 and 8.

22. Antibody according to one of the preceding claims, characterized in that it comprises a heavy chain encoded by a sequence having at least 80% identity with one of the nucleotide sequences SEQ ID NO 1 and SEQ ID NO 25.

23. Antibody according to one of the preceding claims, characterized in that it comprises a heavy chain having at least 80% identity with one of the polypeptide sequences SEQ ID NO 2 and SEQ ID NO 26.

24. Antibody according to one of the preceding claims, characterized in that it comprises a light chain encoded by a sequence having at least 80% identity with one of the nucleotide sequences SEQ ID NO 3 and SEQ ID NO 21.

25. Antibody according to one of the preceding claims, characterized in that it comprises a light chain a sequence having at least 80% identity with one of the polypeptide sequences SEQ ID NO 4 and SEQ ID NO 22.

26. Antibody according to one of the preceding claims, characterized in that it comprises the sequences encoded by the nucleotide sequences SEQ ID NO: 1 and 3.

27. Antibody according to one of the preceding claims, characterized in that its sequence comprises the polypeptide sequences SEQ ID NO: 2 and 4.

28. Antibody according to one of the preceding claims, characterized in that it comprises sequences encoded by the nucleotide sequences SEQ ID NO: 5 and 23.

29. Antibody according to one of the preceding claims, characterized in that its sequence comprises the polypeptide sequences SEQ ID NO: 6 and 24.

30. Antibody according to one of the preceding claims, characterized in that it comprises sequences encoded by the nucleotide sequences SEQ ID NO: 27 and 23.

31. Antibody according to one of the preceding claims, characterized in that its sequence comprises the polypeptide sequences SEQ ID NO: 28 and 24.

32. Antibody according to any one of the preceding claims, characterized in that it induces a reduction of amyloid plaques.

33. Antibody according to any one of the preceding claims, characterized in that its affinity for the protofibrillar form of peptide Aβ is at least 100 times greater than its affinity for the other forms of this peptide.

34. Use of an antibody according to any one of the preceding claims in the treatment of diseases associated with neurodegenerative disorders.

35. Use of an antibody according to any one of the preceding claims in the treatment of Alzheimer's disease.

36. Pharmaceutical composition comprising an antibody according to any one of Claims 1 to 34 and excipients.

37. Method of treatment of Alzheimer's disease, characterized in that it comprises the administration of an antibody according to any one of Claims 1 to 34 to a patient.

38. Cell producing antibodies according to Claim 1 to 34.

39. Method of production of an antibody according to any one of Claims 1 to 34, characterized in that it comprises the culturing of cells according to Claim 38.

40. Medicinal product comprising an antibody according to any one of Claims 1 to 34.

41. Polynucleotide coding for a polypeptide having at least 80% identity with one of the sequences SEQ ID NO: 2, 4, 6, 8, 22, 24, 26 or 28.

42. Polynucleotide, characterized in that it has a sequence having at least 80% identity with one of the sequences SEQ ID NO: 1, 3, 5, 7, 21, 23, 25, or 27.

43. Recombinant vector comprising a nucleic acid according to either one of Claims 41 and 42.

44. Host cell comprising a vector according to Claim 43.