The invention relates to an isolated monoclonal antibody or antigen-binding fragment thereof that (a) binds (i) wild-type Aβ 42/40 protofibril comprising N-terminal truncated Aβ forms and (ii) Aβ 42/40 Arc protofibril comprising N-terminal truncated Aβ forms and (b) has no or little cross-reactivity to Aβ 42/40 monomers. The invention further relates to a method of using such an antibody to treat Alzheimer’s disease.
FIG. 1

A. Monomer wtAβ40

B. Protofibril Aβ42Arc
FIG. 1 (cont.)

C. Protofibril wtAβ42

![Graph showing intensity vs. retention time for protofibril wtAβ42]

D. Fibrils wtAβ42

![Graph showing intensity vs. retention time for fibrils wtAβ42]
FIG. 2 (cont.)

Aβ42arc protofibrils +0.6% Tween-20

Aβ42arc protofibrils

Absorbance 214 nm (AU)

Time (min)

Aβ1-42 arc Protofibril Oligomerization

Peak area Arbitrary Units

Time (min)
FIG. 3

Mouse n, non-immunized mouse (control)
FIG. 4, A

[Graph showing OD (405 nm) against Concentration Aβ (μg/ml) for different states of Aβ: Aβ42 arc protofibrils, wt Aβ42 protofibrils, Aβ Fibrils, Aβ Monomer]
Titration by a sandwich-ELISA of 4 monoclonal antibodies (258, 7E4, 4E11 and 10F7) against wtAβ42 protofibril concentration.
FIG. 4 C

Titration by a sandwich-ELISA of 4 monoclonal antibodies (258, 7E4, 4E11 and 10F7) against wtAβ42 protofibril concentration.
ANTIBODIES SPECIFIC FOR SOLUBLE AMYLOID BETA PEPTIDE PROTOFIBRILS AND USES THEREOF

1. FIELD OF INVENTION

This invention pertains to the diagnosis, prevention and treatment of neurodegenerative diseases, in particular Alzheimer’s disease, and other similar diseases. More precisely, to antibodies that specifically bind amyloid beta protein (Aβ) in its protofibril conformation.

2. BACKGROUND OF THE INVENTION

Alzheimer’s disease (AD) is a progressive and irreversible neurodegenerative disorder causing cognitive, memory and behavioral impairments. It is the most common cause of dementia in the elderly population affecting roughly 5% of the population above 65 years and 20% above 80 years of age. AD is characterized by an insidious onset and progressive deterioration in multiple cognitive functions. The neuropathology involves both extracellular and intracellular amyloid-β (Aβ) protein deposits. The extracellular deposits, referred to as neuritic plaques, mainly consist in amyloid beta protein (Aβ) surrounded by dystrophic neurites (swollen, distorted neuronal processes). Aβ within these extracellular deposits are fibrillar in their character with a β-sheet structure. Aβ in these deposits can be stained with certain dyes e.g. Congo Red and display a fibrilar ultrastructure. These characteristics, adopted by Aβ in its fibrillar structure of neuritic plaques, are the definition of the generic term amyloid. The classic intracellular AD pathologic lesion is the neurofibrillary tangle (NFT) which consists of filamentous structures called paired helical filaments (PHFs) composed of twisted strands of hyperphosphorylated microtubule-associated protein tau. Frequent neuritic plaques and neurofibrillary tangle deposits in the brain are diagnostic criteria for AD, as carried out post mortem. AD brains also display macroscopic brain atrophy, nerve cell loss, local inflammation (microgliosis and astrogliosis) and often congophilic amyloid angiopathy (CAA) in cerebral vessel walls.

Two forms of Aβ peptides, Aβ40 and Aβ42, are the dominant species in AD neuritic plaques (Masters 1985), while Aβ40 is the prominent species in cerebrovascular amyloid associated with AD (Glenner 1984). Enzymatic activities allow Aβ to be continuously formed from a larger protein called the amyloid precursor protein (APP) in both healthy and AD afflicted subjects in all cells of the body. Two major APP processing events, β- and γ-secretase activities enable Aβ production, while a third enzyme called α-secretase activities prevent Aβ generation by cleavage inside the Aβ sequence (Selkoe, 1994; U.S. Pat. No. 5,604,102). The Aβ42 is a forty two amino acid long peptide i.e. two amino acids longer at the C-terminus, as compared to Aβ40. Aβ42 is more hydrophobic, and does more easily aggregate into larger structures of Aβ peptides such as Aβ dimers, Aβ tetramers, Aβ oligomers, Aβ protofibrils or Aβ fibrils. Aβ fibrils are hydrophobic and insoluble, while the other structures are all less hydrophobic and soluble. All these higher molecular structures of Aβ peptides are individually defined based on their biophysical and structural appearance e.g. in electron microscopy, and their biochemical characteristics e.g. by analysis with size-exclusion chromatography/ western blot. These Aβ peptides, particularly Aβ42, will gradually assemble into a various higher molecular structures of Aβ during the life span. AD, which is a strongly age-dependent disorder, will occur earlier in life if this assembly process occurs more rapidly. This is the core of the “amyloid cascade hypothesis” of AD which claims that APP processing, the Aβ42 levels and their assembly into higher molecular structures is a central cause of AD. All other neuropathology of AD brain and the symptoms of AD such as dementia are somehow caused by Aβ or assembled forms thereof.

Aβ can exist in different lengths i.e. 1-39, 1-40, 1-42 and 1-43 and fragments sizes i.e. 1-28, 3-40/42, 11-40/42, 17-40/42 and 25-35. All these peptides can aggregate and form soluble intermediates and insoluble fibrils, each molecular form having a unique structural conformation and biophysical property. Monomeric Aβ1-42 for example, is a 42 amino acid long soluble and non-toxic peptide, that is suggested to be involved in normal synapse functions. Under certain conditions, the Aβ1-42 can aggregate into dipeptides, tetramers, pentamers up to 12-mer and higher oligomeric forms, all with its distinct physicochemical property such as molecular size, EM structure and AFM (atomic force microscopy) molecular shape. An example of a higher molecular weight soluble oligomeric Aβ form is the protofibril (Hartley 1999, Walsh 1999), which has an apparent molecular weight>100 kDa and a curvilinear structure of 4-11 nm in diameter and ~200 nm in length. It has recently been demonstrated that soluble oligomeric Aβ peptides such as Aβ protofibrils impair long-term potentiation (LTP) (Hart-ley, 1999), a measure of synaptic plasticity that is thought to reflect memory formation in the hippocampus (Walsh 2001). Furthermore, oligomeric Arctic Aβ peptides display much more profound inhibitory effect than wtAβ on LTP in the brain, likely due to their strong propensity to form Aβ protofibrils (Klyubin 2003).

There are also other soluble oligomeric forms described in the literature that are distinctly different from protofibrils. One such oligomeric form is ADDL (Amyloid Derived Diffusible Ligand) (Lambert 1998). AFM analysis of ADDL revealed predominantly small globular species of 4.7-6.2 nm along the z-axis with molecular weights of 17-42 kDa (Stine 1996). Another form is called AβPD (Amyloidoidsphe-roids). AβPD are spherical oligomers of Aβ1-40. Toxicity studies showed that spherical AβPD<10 nm were more toxic than lower molecular forms (Hoshi 2003). The Aβ fibril is the main neurotoxic species is inconsistent with the poor correlation between neuritic plaque density and AD dementia score and also with the modest signs of neurodegeneration in current APP transgenic mice. Soluble neurotoxic Aβ-intermediate species and their appropriate subcellular site of formation and distribution could be the missing link that will better explain the amyloid hypothesis. This idea has gained support from recent discovery of the Arctic (E693) APP mutation, which causes early-onset AD (US 2002/0162129 A1; Nilserth et al., 2001). The mutation is located inside the Aβ peptide sequence. Mutation carriers will thereby generate variant of Aβ peptides e.g. Arctic Aβ40 and Arctic Aβ42. Both Arctic Aβ40 and Arctic Aβ42 will much more easily aggregate into higher molecular structures (protofibrils) that are soluble and non-fibrillar. Thus the pathogenic mechanism of the Arctic mutation suggests that the soluble higher molecular protofibrils are causing AD.

2.1 Diagnosis of Alzheimer’s Disease
2.1.1 Clinical Diagnosis

The clinical diagnosis of Alzheimer’s disease (AD) is difficult to make, especially in early stages of the disease.
Today, the diagnosis is based on a typical medical history combined with the exclusion of other causes of dementia. Clinical centres with high specialization can have a diagnostic accuracy of 85-90% compared with the neuropathological diagnosis. In the early stages of the disease the clinical picture is vague and definite diagnostic markers have not yet been identified (McKhann 1984). The development of biochemical diagnostic markers is important for a number of reasons: to support the clinical diagnosis, to allow clinicians to give adequate information to patients and their relatives, to initiate pharmacological treatment and care-giving, and in various aspects of clinical research.

[0009] 2.1.2 Amyloid β-Peptide

[0010] Pathogenic mutations in the APP and presenilin (PS) genes have been discovered in families with early-onset AD inherited as a dominant trait (Hardy 1992). The effects of some of these mutations are now fairly well understood. The Swedish AD mutation (Mullan 1992; Axelman 1994; Lannfelt 1994) has revealed one pathogenic mechanism for the development of AD. When a cDNA construct with this mutation was transfected into human cell-lines it gave rise to approximately six times higher release of soluble Aβ (Citron 1992, Cai 1993). Furthermore, fibroblasts from individuals with the Swedish mutation secreted three times more Aβ into the media compared to fibroblasts from non-carriers (Johnston 1994). Overproduction of Aβ therefore seemed to be an important factor in the disease pathogenesis in this Swedish family. Thus, it was expected that Aβ levels measured in cerebrospinal fluid (CSF) from family members would differentiate carriers from non-carriers of the mutation. However, no difference was found in levels of total Aβ between the groups (14.5±3.3 ng/ml versus 14.9±2.3 ng/ml) (Lannfelt 1995). One explanation for this result may be that Aβ is cleared from CSF by aggregating to amyloid in the brain. However, there was a strong correlation between duration of dementia and decreasing Aβ levels. These measurements were done with antibodies recognizing soluble monomeric Aβ. With protifibril specific monoclonal antibodies more accurate measurements of the toxic species will be possible.

[0011] 2.1.3 Aβ in Plasma

[0012] Aβ is found in a soluble form in plasma and other tissues (Seubert 1992), and not as previously presumed, only in the brains of AD cases. Aβ plasma levels in members of the Swedish mutation family revealed that both Aβ40 and Aβ42 were 2-3 times increased in mutation-carriers (Scheuner 1996). The proportion of Aβ42 of total Aβ was approximately 10% in both groups, which is in agreement with experiments performed in cell cultures with the Swedish mutation. Mutation-carriers below the age of expected onset of the disease had the same levels of MS as already affected cases. This indicates that APP mismetabolism may play an important role early in the pathogenesis of the disease.

[0013] 2.1.4 Aβ42 in CSF in Alzheimer’s Disease

[0014] ELISAs specifically measuring Aβ40 and Aβ42 in CSF in AD cases have given different results. Some researchers (Pirtttilä 1994, Motter 1995) have found decreased Aβ42 in AD, while one group have found elevated levels in cases early in the disease progression. The most demented cases in one study had all very low levels of Aβ42. In conclusion, Aβ42 is most likely increased early in the disease process and levels of Aβ42 and Aβ40 decreased during progression of the disease. The development of accurate biochemical markers of early AD is important especially when efficient pharmacological therapy will be available in the future. Pharmacological therapy should most likely be initiated at an early stage of disease, before severe brain damage has occurred. A therapy delaying it possible to prevent the progression of the disease to its later stages would therefore be much desired.

[0015] 2.2 Prevention and Treatment of Alzheimer’s Disease

[0016] Antibodies that are specific towards different conformations of Aβ, such as Aβ fibrils (O’Nuallain 2002), micellar Aβ (Kayed 2003), AβDL (M93, M94) (Lambert 2001) have also been described.

[0017] Several pre-clinical studies in transgenic animal models have shown decreased plaque burden and improvements in memory function after active or passive immunization with antibodies raised against fibrils (Shenk 1999, Janus 2000, Morgan 2000, Weiner 2000, Sigurdson 2001). Since fibrils are present in pathological deposits occurring late in the Alzheimer disease process, the Shenk antibodies may only be used to slow the progression of Alzheimer’s disease when it has already reached its later stages.

[0018] Recently, a phase II clinical trial in Alzheimer patients with mild to moderate dementia was performed by ELAN Pharmaceuticals with their vaccine AN 1792, which is an aggregated preparation of human wtAβ42. The study had to be stopped due to side effects in 5% of the patients. The side effect was considered to be due to T-lymphocyte-induced meningoencephalitis (Niehoff 2001). The drug targets of the ELAN vaccine were insoluble fibrils found in plaques inside the brain and deposits on the brain blood vessel walls (Congoophilic Amyloid Angiopathy, CAA), which are common features of Alzheimer’s disease. Thus, an immune response towards insoluble fibrils could be responsible for the invasive inflammation in the brain blood vessel walls leading to meningoencephalitis.

[0019] WO02/203911 disclose the discovery of the Arctic mutation in a Swedish family leading to early onset of Alzheimer’s disease (55.6 years). The Arctic mutation (Glu>Ala), which is located at position 22 in the beta amyloid peptide (Aβ), in combination with various experiments led to the insight that the Aβ peptide was much more prone to oligomerize and form protofibrils compared to wild type Aβ40. The discovery indicated for the first time that the protofibril is a central component in the disease process, and that AD could be treated by reducing the amount of protofibrils in the brain. This unique property of the Arctic mutation could then be used to generate protofibrils. WO02/203911 then suggested that said protofibrils could be used to immunize a mouse or other animal, in order to generate antibodies, after which any protofibril-specific monoclonal antibody could be identified by screening. Said antibodies should then be specific towards an Aβ peptide of SEQ ID No 1 (page 7, paragraph 1), i.e. a peptide carrying the Arctic mutation and having a protofibril conformation.

[0020] Thus, in view of the prior art techniques for preventing and treating Alzheimer’s disease, there is a need for a technique that enables earlier detection of markers of Alzheimer’s disease. If said markers could be prevented without causing negative side-effects, this would be a means to prevent and treat Alzheimer’s disease at an early stage. Any treatment of Alzheimer’s disease that would reduce the amount of protofibrils in the brain of AD patients, would be of significant therapeutic value.
3. DESCRIPTION OF THE INVENTION

[0021] Protofibrils occur early in Alzheimer’s disease, when little brain damage has occurred. An antibody treatment that reduce protofibril levels in the brain will save the brain from neuronal destruction and hence be more advantageous for Alzheimer patients. The present invention describes the development of such therapeutic protofibril specific antibodies.

[0022] According to one aspect, the present invention relates to antibodies that have the property to bind both wild type Aβ42/40 and Aβ42/40arc protofibrils (conformation-specific antibodies) and which are suitable for development into pharmaceuticals for Alzheimer’s disease, targeting wild type Aβ42/40 protofibrils. Current ideas in the field of Alzheimer’s disease research is that Aβ fibrils are the main cause of the disease. Hence, the approach of the present invention contradicts the general opinion within the field.

[0023] According to another aspect, the present invention also relates to a composition comprising said antibody and optionally a carrier or excipient.

[0024] To immunise and screen for conformation-specific anti-protofibril antibodies, it is necessary to produce pure Aβ42arc and Aβ42 protofibrils (>95% degree of purity). In order to obtain said pure protofibril preparation, it is also necessary to be able to stabilise the protofibrils, such that they stay protofibrils and do not separate into monomers or aggregate into fibrils. It is also necessary to find a solvent that made it possible to separate the protofibrils by column chromatography. Another necessity is the ability to test said purity before immunisation. The above-mentioned abilities are essential, since the degree of purity of the antigen (protofibrils) decide the possibility to produce conformation-specific anti-protofibril antibodies, which in turn decide the possibility to screen for antibodies with useful specificity. Should the preparation for example contain 50% Aβ monomer and 50% Aβ protofibril, it is only possible to claim that the antibody binding said preparation may bind both forms or only one. All of said necessary features are provided by the present invention.

[0025] The above-mentioned features were not possible when WO02/203911 was filed. The HPLC analysis method disclosed it the present application or any other analysis method had not been developed, wherefore it was not possible to determine whether the Aβ42arc peptide actually formed protofibrils, probably due to the lack of binding to protofibrils. It was only a hypothesis at the time. The major reasons why WO002/203911 could not analyse and purify protofibril preparation to a degree of purity of >95%. Also, to the fact that they did not know how to stabilise protofibrils. In that connection, it should also be mentioned that protofibrils are very difficult to handle in comparison with for example Aβ40 peptides. Aβ42, but in particular the Aβ42Arc peptide, is extremely difficult to handle, since they stick to test tubes and columns and aggregate into fibrils. The latter problems has been solved by the present invention by the provision of methods to stabilise the protofibrils involving low temperatures and selected solvents. WO02/203911 also had no means for testing the purity of the protofibril before immunisation. This is possible with the present invention by the provision of a new HPLC (size exclusion) method. In addition to this, WO02/203911 did not provide any means to check the protofibril specificity of the screened antibodies. The present invention makes this possible by the provision of a new Elisa method. WO02/203911 could only produce impure and transient Aβ40arc protofibrils, not useful for monoclonal development of protofibril specific antibodies (WO002/203911 only describes analysis of Aβ40 and Aβ40Arc peptides, see Example 3).

[0026] The antibodies according to the present invention are particularly suitable for treating Alzheimer’s disease since they will: i) target and eliminate the most toxic Aβ form (protofibril), ii) provide an opportunity to treat the disease early since protofibrils develops early in the disease process, iii) avoid side-effects since the will not significantly cross-react with Aβ fibrils present in the blood vessel wall of the brain (CAA—Congophilic Amyloidogenic Angiopathy).

[0027] The antibodies according to the present invention may be human or humanised, monoclonal or polyclonal. The present invention also relates to biologically active fragments of said antibodies, with the proviso that they still have the claimed properties.

[0028] The Aβ protofibril specific antibodies according to the present invention can also be used to quantitate wild type Aβ42/40 protofibrils in biological fluids, thus the antibodies will be suitable for clinical diagnosis at an early stage of the disease and suitable as a biomarker to monitor efficacy in clinical studies.

[0029] Furthermore, the invention describes procedures to generate wild type Aβ42 and Aβ42arc protofibrils as antigens for immunization and for reagents to screen for antibodies that binds Aβ42arc and wild type Aβ42 protofibrils. Antigen (protofibril) purity is very important to determine in antibody screening experiments, since it affects antibody specificity determinations by ELISA.

[0030] To assess the purity of antigen (Aβ42arc and wild type Aβ42 protofibrils) preparation, a size exclusion HPLC method has been developed. The HPLC method invented uses a detergent, with low optical interference in chromatography. The detergent has the advantage that it eliminates interactions of Aβ42arc and wild type Aβ42 protofibrils with the column matrix, preventing loss of material and material from adhering to the column, and erroneous estimations of protofibril purity. Furthermore, the detergent is compatible with Aβ protofibrils and does not solubilize them into Aβ monomers or alter their biological profile. Polymeric (Tween) has been found to be a suitable detergent, in particular Polysorbate-80 (Tween-80). Other detergents with similar properties are also useful.

[0031] The antibody according to the present cross-reacts less than 50% with Aβ fibrils. Said antibody can detect both wild type Aβ protofibrils and Arctic Aβ protofibrils in an ELISA in a concentration range of 1000-10 ng/ml (see Example 5 and FIGS. 4A-C). In an optimised ELISA or by other detection systems with higher sensitivity, for example proximity ligation, said detection level could probably be brought down to a detection level of 1-0.1 ng/ml.

[0032] The present invention provides a method to raise antibodies that are specific to amyloid β (Aβ) protofibrils (high molecular weight soluble non-fibrillar Aβ oligomers). The antibodies are raised against Aβ in its protofibril conformation. These antibodies will be administered to AD patients to reduce protofibril levels in the brain, which will be of significant therapeutic value.

[0033] The lowering of protofibril levels might occur through the elimination of the antigen when bound to an antibody, through microglia-mediated phagocytosis. This is a well documented biological process, which occurs through the binding of the antibody’s constant region (Fc) to an Fc
receptor on microglial cells. Binding induces phagocytosis (internalisation and destruction) of the antibody and its bound antigen (protofibril) leading to reduced levels of protofibrils in the brain. Other non-Fc receptor mediated processes might also occur to eliminate the antigen (protofibril).

Another aspect of the invention pertains to a method to synthesize Aβ protofibrils which are to be used as antigen for immunization. The synthesis can be made from wild type Aβ (wtAβ) or alternatively, from non-wild type, mutated or modified forms of Aβ. In a preferred embodiment of the invention, the but not to said embodiment, the synthesis is initiated by dissolving wtAβ42 in a dissociating agent, for example NaOH, to achieve a homogeneous Aβ solution, of about 50-500 μM in peptide concentration, but not limited to this concentration. Alternative agents with dissociating capacity are for example dimethylsulfoxide, DMSO; hexafluoroisopropanol, HFIP; trifluoroacetic acid and TFA. Wild type protofibrils can also be made from wtAβ peptides of different lengths i.e. wtAβ1-39, wtAβ1-40, wtAβ1-43 or N-terminal truncated forms of these peptides. The truncation can be 1-10 amino acids, giving wtAβ forms such as wtAβ2-42, wtAβ3-42, wtAβ4-42, wtAβ5-42 and so on. The dissolved wtAβ1-42 peptide is subsequently neutralized by PSS or similar physiological buffer and incubated at higher temperature, preferably 37° C., for a period of time sufficient for protofibril-formation to occur, for example over night. This will yield wild type Aβ protofibrils. The invention also provides a molecular size (molecular weight) determination method to assess protofibril formation and purity, preferably, but not limited to, a size-exclusion chromatographic method (SEC).

The method of synthesizing pure wild type (wtAβ42) protofibril antigen, comprises the steps of dissolving an wtAβ42 by using a dissociating agent, such as NaOH (pH>10), dimethylsulfoxide, DMSO; hexafluoroisopropanol, HFIP, trifluoroacetic acid and TFA, to achieve a monodisperse solution, neutralizing the solution by PBS (pH 7-8) or similar biocompatible buffers, to achieve a physiological solution, incubating the neutralized wtAβ42 peptide solution at an elevated protein concentration between 1-1000 μM, preferably 440 μM, for 6 hours or longer at 20-40° C, preferably 37° C, to form Aβ42wt protofibrils, diluting the protofibrils to approximately 1-500 μM, preferably 50 μM centrifugating at sufficient speed and time to sediment wtAβ42 fibrils, which normally takes 5 minutes at 17,000g at 4° C, assessing the purity of the protofibril preparation by HPLC to control that the purity is ≥95%, using for example size exclusion HPLC, using a physiological buffer such as PBS at neutral pH as running buffer, including a detergent, such as Polysorbate (Tween), or similar detergent, to avoid sticking of the protofibrils to the column matrix and dissociation.

Another aspect of the invention, pertains to the synthesis of non-wild type Aβ protofibrils using Aβ1-42, Aβ1-41, Aβ1-40 or Aβ1-39 or N-terminal truncated forms (1-10 truncations) with either the Arctic (G22E) mutation (U.S. Ser. No. 60/899,815), the Dutch mutation (E22Q), the Flemish (A21G) mutation, the Italian (E22K) mutation, the Iowa (D23N) mutation, and combinations thereof. In a preferred embodiment of the invention Aβ42arc peptide (i.e., comprising the arctic mutation) is used. The method to make Aβ42arc protofibrils is similar to that for wtAβ42 protofibrils except that Aβ42arc protofibrils are not incubated at 37° C over night since they are spontaneously formed after the neutralization step.

The method of synthesizing pure Aβ42arc protofibril antigen comprises the steps of dissolving an Aβ42arc peptide by using a dissociating agent, such as NaOH (pH>10), dimethylsulfoxide, DMSO, hexafluoroisopropanol, HFIP; trifluoroacetic acid and TFA to achieve a monodisperse solution, neutralizing the solution by PBS (pH 7-8) or similar biocompatible buffers, to achieve a physiological solution, stabilizing the spontaneously formed protofibrils by keeping them at below 20° C, preferably at 0-5° C, centrifuging the protofibrils, at the same temperature as in the stabilizing step, at a sufficient speed and time to sediment Aβ42arc fibrils, which normally takes 5 minutes at 17,000g at 4° C, assessing the purity of the protofibril preparation by HPLC to control that the purity is ≥95%, using for example size exclusion HPLC, using a physiological buffer such as PBS at neutral pH as running buffer, including a detergent, such as Polysorbate (Tween), or similar detergent, to avoid sticking of the protofibrils to the column matrix and dissociation.

Another aspect of the invention pertains to the development of antibodies that cross-react with wild type Aβ42 protofibrils after immunization with Aβ42arc protofibrils.

Another aspect of the invention pertains to a method to stabilize Aβ protofibril and where stabilization can be assessed by size-exclusion chromatography (SEC). Aβ protofibrils elutes after 12-13 minutes in a uniform peak on a Superdex 75 or similar size-exclusion column. Conformation stability can also be assessed by staining with Congo Red and (electron microscopy), where protofibrils attain a curve-linear structure of 6-10 nm in diameter and<200 nm in length. Lowered temperature has a significant effect on Aβ protofibril conformational stability. Samples should preferably be kept below 20° C, preferably below 5° C, and most between 0° C and 5° C. Furthermore, agents that decrease the polarity or surface tension or increase viscosity have stabilizing effects on Aβ protofibril conformation. For example, 10-50% glycerol or 0.6-5% Polysorbate (Tween), have stabilizing effects on Aβ protofibrils. These agents and treatments can be added to the Aβ protofibril preparation preferably after the neutralization step in the method to synthesize Aβ protofibrils described above. Addition of these agents before this step is also possible. Increased stability of protofibrils is advantageous when developing monoclonal antibodies and when Aβ protofibrils are used as reagents in immunoassays, such as ELISA, radio-immunoassay (RIA), Western blotting or dot blotting.

The method of stabilizing the Aβ protofibrils includes mixing them with an agent that decreases the solvent polarity or one that lowers the surface tension, such as glycerol or Polysorbate (Tween), or a combination of said agents. The stabilisation can also be achieved by keeping the protofibrils at a temperature below 20° C, preferably 0-5° C. Said methods can also be combined.

The invention further pertains to the use of anti-Aβ protofibril specific antibodies for determinations of Aβ protofibrils in human and animal tissues, for example, cerebrospinal fluid, blood, serum, urine and brain tissue, but is not limited to these tissues, providing for a possible diagnostic method for Alzheimer’s disease. Suitable methods for assaying Aβ protofibrils in these tissues as well as in cell cultures using an anti-Aβ protofibril antibody are immunoassays such as ELISA, RIA, Western blotting dot blotting or proximity ligation. The method would be suitable to follow treatment
efficacy (protophil reduction) in clinical trials and suitable as a diagnostic test for Alzheimer’s disease or Down’s syndrome.

[0042] The method of diagnosing or monitoring Alzheimer’s disease (AD) or Down’s syndrome comprises the steps of labelling the antibody according to the present invention with an agent that can generate a measurable signal, administering said antibody according to a subject having or suspected of having AD or Down’s syndrome, measuring the amount of protophils bound to the antibody by measuring the signal generated by the agent.

[0043] The invention further pertains to the use of an anti-
Aβ protophil antibody in imaging for detection, localization and quantitation of Aβ protophils in human and animal tissues. The anti-Aβ protophil antibody could be label with a radioactive ligand such as 111In, 3H or Gallium56, but it is not limited to these radioisotopes, for detection purposes. In addition to labelling with radioactive markers, DNA, fluorescent molecules, enzymes which converts a substrate such that its absorbance can be measured, could also be used. The method will be suitable as a diagnostic tool for Alzheimer’s disease or Down’s syndrome, Lewybody dementia, vascular dementia, and other neurodegenerative disorders.

[0044] A further aspect of the invention pertains to the use of an anti-Aβ protophil antibody for the prevention or treatment of Alzheimer’s disease. Pre-clinical studies in transgenic animal models have demonstrated effects on plaque burden (Bard 2000), reversal of memory deficits (Dodard 2002) and drainage of Aβ from CNS after anti-Aβ antibody treatment. However, the antibodies used in these studies have not been specific to Aβ protophils. Administration of an anti-Aβ protophil antibody, with or little cross-reactivity towards Aβ monomers and fibrils would be particular suitable for treatment and prevention of Alzheimer’s disease. Firstly, it would not bind significantly to fibrillar forms of Aβ and avoid interaction with fibrillar deposits which are prevalent in blood vessels walls, avoiding severe immunoreactions with concomitant serious brain inflammation and encephalitis, which was encountered in the ELAN vaccination study (see at the end of the Background) with their vaccine AN-1792 (Nicoll 2004). Secondly, an anti-Aβ protophil antibody with low Aβ1-40 and Aβ1-42 monomer cross-reactivity would not bind and interfere with their normal biological functions, thus avoiding side effects.

[0045] In said method of prevention or treatment of Alzheimer’s disease or Down’s a subject having or suspected of having Alzheimer’s disease, Down’s syndrome, Lewybody dementia, vascular dementia, and other neurodegenerative disorders, is administered the antibody or composition according to the present invention.

[0046] The invention also provides a technique whereby anti-Aβ protophil antibodies can be used to identify and select for epitopes present on Aβ protophils but loss on Aβ monomers and Aβ fibrils or other Aβ conformational forms. The method is general and is applicable to other amyloids forming protophils such as, but not limited to, islet amyloid protein peptide (IAPP, amylin) associated with Type-2 diabetes, prion protein (PrP), alpha-synuclein (Parkinson). Considering the central role of amyloid beta (Aβ) protophils in Alzheimer’s disease, these antibodies can be used to diagnose or treat Alzheimer’s disease. There is a need for a method that specifically can determine protophils in different human and animal tissues such as cerebral spinal fluid (CSF), plasma, blood, urine and brain tissue, but is not limited to these tissues. Such a method could be used as a diagnostic method for Alzheimer’s disease but also for similar diseases that forms amyloid protophils including Parkinson (alpha-synuclein) (Stählerman 2002), Type-2 diabetes (islet amyloid polypeptide, IAPP) (WO03/02619 A2), and Creutzfeldt-Jacob Disease and the corresponding animal disease called mad cow disease (Prion protein) (DeMarco 2004), but is not limited to these diseases.

[0047] According to another aspect, the present invention relates to the use of anti-Aβ protophil antibodies for in vitro or in vivo screening of substances that inhibit or modulate Aβ protophil levels and/or activity in cell cultures or animal models, being potential Alzheimer drugs. Suitable screening systems would be, but are not limited to, cell cultures (EEC or neuroblastoma cells) or for example the THY-1 APPSweArc transgenic mouse model, (Nilsson L. et al. Swedish patent application 0400707-6, 2004) that expresses human Amyloid Precursor Protein (APP) with the Arctic mutation (E693G) providing increased production of Aβ protophils. Alzheimer drug candidates can be administered to these cell cultures or transgenic animal models and their effects on Aβ protophil levels measured by an immunoassay, using an anti-Aβ protophil antibody as reagent. Such method would be ideally suitable for identifying potent Alzheimer drug candidates.

[0048] Said method for in vitro or in vivo screening of substances that inhibit or modulate Aβ protophil levels and/or activity in cell cultures or animal models, comprises the steps of administering potential drug candidates to a cell culture or an animal model, administering the antibody according to any the present invention, labelled with an agent that can generate a measurable signal, to said cell culture or animal model, evaluating the effect of said drug candidates by measuring the amount of protophils bound to the antibody by measuring the signal generated by the agent.

[0049] According to another aspect, the present invention relates to a method of detecting Aβ protophils in vitro, comprising labelling the antibody to the present invention with an agent that can generate a measurable signal, contacting said antibody or the composition comprising the antibody with a biological sample suspected of containing soluble protophils, measuring the amount of protophils bound to the antibody by measuring the signal generated by the agent. Said method may be an immunoassay. The biological samples tested may be selected from plasma, CSF, brain and other tissues of animal or human origin. The labelling includes, labelling with radioactive markers, DNA, fluorescent molecules, enzymes which converts a substrate such that its absorbance can be measured.

[0050] All percentages in the description relates to percent volume, unless stated otherwise.

4. DESCRIPTION OF THE DRAWINGS

[0051] FIG. 1A to FIG. 1D. Size exclusion chromatography (SEC) of Human Monomer Aβ40, Protophil Aβ42, Prototibril wtAβ42 and Fibril wtAβ42 preparations Human Aβ monomers and Aβ protophils are eluting in 19-20 minutes and at 12-13 minutes, respectively. The protophil preparations (B and C) are essentially free (~3%) from contamination of other conformational Aβ forms. The analysis of the fibril preparation (D) was done after centrifugation at 17,900g for 5 minutes at room temperature. The supernatant was analysed demonstrating the almost complete absence of any soluble Aβ forms in the fibril preparation.
The stability of protofibril AB42Arc and protofibril wt42 preparations was measured by SEC. A conversion of protofibrils to fibrils was assessed by a decrease in the fibril protopel peak area (decreased absorbance (AU)) at 214 nm elution time 12-13 minutes). The addition of 10-50% glycerol, 0.6% Tween-20 or storage at 0-3°C, all increased the protofibril stability significantly.

Fig. 3: Titration of mouse serum after immunization with protofibril wtAβ42. Mice were immunized with a protofibril wtAβ42 preparation in Freund complete adjuvant (first injection) and incomplete Freund adjuvant Aβ (5-6 boosters). Blood was collected and the antibody titers against Aβ protofibrils were determined. Mice #2 and #4 showed the highest titers.

Fig. 4A & 4C: Sandwich-ELISA method using anti-mAb 258 for Aβ protofibril determination. mAb 258 was coated overnight in a microtiter plate. Preparations of wtAβ42 protofibrils, Aβ42 Arc protofibrils, wtAβ40 monomers and wtAβ42 fibrils were added in decreasing concentrations and incubated for 1 hour at 44°C. Secondary anti-Aβ antibody (6E10) was added. Finally, a detection ALP (alkaline phosphatase) conjugated antibody (anti-IgG) was added to each well. Detection was achieved by adding ALP substrate. The colour formation was measured in 405 nm and 492 nm. mAb 258 bound wtAβ42 protofibrils and slightly less Aβ42 Arc protofibrils. No binding was observed to wtAβ40 monomers. The slight binding to wtAβ42 protofibrils is probably due to a slight contamination with wtAβ42 protofibrils (see Fig. 1 D).

5. EXAMPLES

The following examples are provided for illustration and are not intended to limit the invention to the specific examples provided.

Example 1

Synthesis of Human Amyloid Beta Peptide (Aβ) of Different Conformations

Synthetic human wild type or mutant forms of Aβ1-42 or Aβ1-40 peptides were purchased from Polypeptide Laboratories GmbH. The peptides had been synthesized by a standard solid phase peptide synthesis procedure. The peptides were subsequently purified with RP-HPLC to a purity in the range of 90-95%. Alternative vendors producing Aβ peptides with similar purity are possible to use as well.

Synthesis of Human Wild Type Aβ1-40 Monomers

A synthetic wtAβ1-40 peptide was dissolved in 1 volumes of 10 mM NaOH pH1-10, and 1 volume of cold 2xPBS (pH 7-8) to a concentration of 50 uM. The wtAβ1-40 monomer preparation was centrifuged at 17,900 x g at +4°C for 5 minutes prior to analysis (Fig. 1).

Synthesis of Human Wild Type Aβ1-42 Protofibrils

A synthetic wtAβ1-42 peptide was dissolved in 9 volumes of 10 mM NaOH pH1-10, vortexed for 2 minutes and diluted with 1 volume of 10xPBS (pH 7-8). The final peptide concentration was at this point 445 uM. The peptide was further incubated overnight at 37°C. After the overnight incubation, the peptide was further diluted with PBS to 50 uM. The sample was centrifuged for 17,900 x g for 5 minutes prior to analysis and immunisation.

Synthesis of Human Wild Type Aβ1-42 Fibrils

A synthetic wtAβ1-42 peptide was dissolved in 1 volume of distilled water, vortexed for 2 minutes and diluted with 1 volume of 1xPBS (pH 7-8) and vortexed again for 2 minutes. The final peptide concentration at this point was 50 uM. The wtAβ1-42 fibril preparation was incubated at 37°C for 48 hours before analysis. The sample was centrifuged at 17,900 x g for 5 minutes prior to SEC analysis. The supernatant was analysed after centrifugation. No centrifugation was performed when Aβ1-42 fibril preparations were analysed by ELISA or dot blotting.

Analysis of Aβ Preparations by Size Exclusion Chromatography (SEC)

A Merck Hitachi D-7000 HPLC LaChrom system, having a diode array detector (DAD) model L-7455 and a model L-7100 pump, was used for the chromatographic analysis of protofibril preparations in combination with a Superdex 75 PC3.2/30 column (Amersham Pharmacia Biotech, Uppsala, Sweden). The chromatographic system separates Aβ monomers from protofibrils, which are eluting at the void volume of the column. The column was equilibrated with 50 mM Na2HPO4 NaH2PO4 (pH 7.4) with 0.15 M NaCl (PBS) and 0.6% Tween 20 and eluted with the same buffer at a flow rate of 0.08 ml/min (pressure was 5-6 bars) at ambient temperature (22°C). Ten (10 μl) of a 50 uM-100 uM Aβ sample was subjected analysis using a wavelength scan between 200-400 nm. Tween-20 was added to the sample to give a final concentration of 0.6% prior to chromatography. Data was extracted from measurements at 214 and 280 nm. Peaks were integrated using Merck Hitachi model D-7000 Chromatography Data Station. Software. Fig. 1 shows chromatograms of wtAβ1-40 monomer, wtAβ1-42 protofibril, Aβ1-42 Arc protofibril and wtAβ1-42 fibril preparations.

Each preparation was essentially free (≤3%) of other contaminating conformational Aβ forms except the wtAβ1-40 monomer preparation which contained 6.4% protofibrils (elution time 12-13 minutes).

Example 2

Protofibrils Specific Monoclonal Antibody Development

A standard procedure was used for monoclonal development. Mice were injected with wtAβ1-42 protofibril preparation. Alternatively, Aβ1-42 Arc protofibrils could be used. Every wtAβ1-42 protofibril batch was assayed by SEC and Congo Red (binds β-sheet structures in proteins) before immunisation to ascertain protofibril purity and that the preparation contained β-sheet structure. The procedure used to immunise mice was a standard protocol involving s.c. injections in the presence of Freund adjuvant. Each of six mice were immunized with 10 μg wtAβ1-42 protofibrils and sub-
subsequently boostered with 30 ug. The sample was mixed 1:1 with Freund complete adjuvant prior to the first injection. For subsequent 5 booster injections incomplete Freund adjuvant was used. Mice were bleed and blood collected for antibody titer determinations (FIG. 3). Mice were given one more booster (30 ug) and then sacrificed and the spleen collected for hybridom development. The hybridom preparation method used was according to standard procedure (Harlow 1988).

Example 3

Screening for wtAβ1-42 Protopilibr Specific Antibodies

An ELISA method was developed where by hybridom supernatants were screened for antibodies that bind Aβ1-42 protopilibr. Hybridom supernatant #258 showed high protopilibr specificity (FIG. 3). The hybrid #258 was reseeded and screened again to ascertain a homogenous cell line. The monoclonal antibody that was produced from the #258 hybridom was defined as monoclonal antibody 258 (mAb258). Alternatively, screening (binding to Aβ protopilibr but not to Aβ monomers or fibrils) can be performed against an antibody phage display library, where the library has been made from RNA isolated from animals immunized with protopilibr.

Example 4

Characterization of mAb 258 by Western Blot Analysis

The aim of the experiment was to determine if mAb 258 cross-reacts with wild type human amyloid precursor protein (wtAPP) or mutated human APP, APPswae, APP sware (Nilsberth 2001, Malian 1992) all of which contains uncleaved Aβ1-42. Cells were transfected with plasmids expressing human wtAPP, APPswae and APPswae-arc. Cells were subsequently harvested and solubilized and cellular proteins separated by SDS-PAGE and transferred to nitrocellulose filter papers and subsequently incubated with either mAb 258 or mAb 6E10. Specific binding of these antibodies to separated cellular proteins was detected by incubating the filter papers in a secondary anti-mouse IgG/IgM antibody solution and subsequently developed by incubation with Pierce super signal (art nr 34080-P) and a light sensitive film.

mAb 258 showed no binding to wtAPP, APPswae or APPswae-arc nor to wtAβ40 monomer. The commercial mAb 6E10 bound all these forms.

Example 5

Sandwich ELISA for Protopilibr Characterization and Determinations

The specificity of mAb 258 was determined by a sandwich-ELISA.

An 96-well ELISA plate was coated with mAb 258 over night at +4°C. After coating, wells were blocked with BSA for 1 hour at room temp. Aβ1-42 monomers, Aβ1-42 protopilibr, Aβ1-42-Arc protopilibr were added to the microtiterplate in 5x dilutions starting with 10 ng/ml. Samples were incubated for 1 hour at +4°C, after which 10 ng/well of a commercial secondary antibody, 6E10 (Signet) was added and incubated for 1 hour at room temp. Detection was achieved by incubation with a commercial ALP-conjugated anti-IgG antibody for 1 hour at room temp. and subsequent incubation with the substrate at room temp. for one hour according to the manufacturer’s procedure. Samples were read in a microtiterplate reader (Spectra max 190 Molecular Devices, Sunnyvale, USA) at 405 nm and 492 nm. FIG. 4A.

mAb 258 showed little or no cross-reactivity towards wtAβ40 monomers or wtAβ42 fibrils. Concentrations of wtAβ42 protopilibr down to 10 ng/ml were measurable.

Binding of an anti-Aβ42arc protopilibr specific antibody (7E4) (Aβ42arc in protopilibr conformation was used as a antigen during immunization) was measured in the sandwich-ELISA coated with increasing concentrations of wtAβ42 protopilibr. Detection was achieved by either an Aβ-specific mAb (1C3) as a secondary detection antibody (FIG. 4B) or by the commercial mAb 6E10, as secondary antibody (FIG. 4C). Strong binding of mAb 7E4 was achieved to wtAβ42 protopilibr. Concentration levels as low as 2-5 ng/ml of wtAβ42 protopilibr were measurable. The monoclonal antibodies 4E11 and 10F7 show less strong binding to wtAβ42 protopilibr (FIGS. 4B and 4C).

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1. An antibody specific for soluble amyloid beta peptide (Aβ) protofibrils and/or biologically active fragments thereof.

2-36. (canceled)

37. A method for lowering Aβ protofibril levels in the brain of a subject comprising administration to the subject an antibody or antigen-binding fragment thereof that binds Aβ40/42 arc protofibril and Aβ40/42 wild-type protofibril and has no or little cross-reactivity to Aβ40/42 monomers.

38. The method of claim 37, wherein the antibody or antigen-binding fragment thereof is monoclonal.

39. The method of claim 37, wherein said antibody is an antigen-binding fragment.

40. The method of claim 37, wherein said antibody is humanized.

41. The method of claim 37, wherein said antibody is produced by immunizing and screening with at least 95% pure Aβ40/42 arc protofibril.

42. The method of claim 37, wherein said antibody is produced by immunizing and screening with at least 95% pure Aβ40/42 protofibril.

43. The method of claim 37, wherein said antibody is a protofibril conformation specific antibody or antibody fragment.

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SEQUENCE LISTING

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<212> TYPE: PRO
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<400> SEQUENCE: 1

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Gly Leu Leu Met Val Gly Val Val Ile Ala
35   40