HUMAN ANTI-ALPHA-SYNUCLEIN AUTOANTIBODIES

Field of the invention

The present invention generally relates to novel α-synuclein-specific binding molecules, particularly human antibodies as well as fragments, derivatives and variants thereof that recognize α-synuclein and aggregated forms of α-synuclein, respectively. In addition, the present invention relates to pharmaceutical and diagnostic compositions comprising such binding molecules, antibodies and mimics thereof valuable both as a diagnostic tool to identify toxic species of α-synuclein in plasma and CSF and also in passive vaccination strategies for treating disorders related to aggregates of α-synuclein such as Parkinson's disease (PD), dementia with Lewy bodies (DLB) and Lewy body variant of Alzheimer's disease (AD) and other synucleinopathic diseases.

BACKGROUND OF THE INVENTION

Protein misfolding and aggregation are pathological aspects of numerous neurodegenerative diseases. Aggregates of α-synuclein are major components of the Lewy bodies and Lewy neurites associated with Parkinson's disease (PD). A natively unfolded protein, α-synuclein can adopt different aggregated morphologies, including oligomers, protofibrils and fibrils. The small oligomeric aggregates have been shown to be particularly toxic.

Naturally occurring autoantibodies against α-synuclein have been detected in healthy persons and altered levels in patients were associated with particular neurodegenerative disorders; see for review Neff *et al.*, Autoimmun. Rev. 7 (2008), 501-507. Thus, naturally occurring antibodies in patients suffering from Parkinson's disease, either spontaneously or upon vaccination, in particular in healthy patients may serve a protective role with respect to α-synuclein aggregation; see, *e.g.*, Woulfe *et al.*, Neurology 58 (2002), 1435-1436 and Papachroni *et al.*, J. Neurochem. 101 (2007), 749-756. Hitherto, the therapeutic significance of autoantibodies had been difficult to assess. This is mostly due to the lack of straight-forward experimental approaches for their isolation and subsequent characterization *in vitro*.

Recently, oligomeric species of α-synuclein have been reported extracellularly in plasma and CSF (El-Agnaf *et al.*, FASEB J. 20 (2006), 419–425) and immunization studies in mouse models of PD show that extracellular mouse monoclonal antibodies against α-synuclein can reduce accumulation of intracellular α-synuclein aggregates (Masliah *et al.*, Neuron, 46 (2005), 857–868) supporting the idea that antibodies that neutralize the neurotoxic aggregates without interfering with beneficial functions of monomeric α-synuclein may be useful therapeutics. However, the therapeutic utility of murine based antibodies in human is hampered by the human anti-mouse antibody (HAMA) response in view of their non-human origin.

Emadi *et al.* in J. Mol. Biol. 368 (2007), 1132–1144, describe the isolation of single chain antibody fragments (scFvs) from a phage displayed antibody library based on human sequences against α-synuclein, which bind only to an oligomeric form of α-synuclein and inhibit both aggregation and toxicity of α-synuclein *in vitro*. However, although the generation of scFvs from phage display is rather simple, this technique has severe drawbacks since the antibodies so produced bear the risk of undesired crossreactivity against self-antigens and lack the characteristics of evolutionary optimized natural human antibodies produced by the human immune system. Furthermore, such antibodies may not be specific enough because of cross-reactivity with other proteins and/or with the target protein in context with normal physiological environment and function. In case of Parkinson's disease, for example, antibodies that also cross-react with physiological derivatives of α-synuclein bear the potential to cause side effects related to the normal functions of the physiologic target structures. In this respect, an undesired autoimmune disease would downrightly be induced – a hardly calculable risk also in the conceptual design of active immunization experiments employing protein structures that, in variant form, also occur physiologically.

More recently, Seitz *et al.* (81. Kongress der Deutschen Gesellschaft für Neurologie mit Fortbildungsakademie Hamburg 10.-13.09.2008), reported on the isolation of anti-α-synuclein polyclonal autoantibody from different immunoglobulin solutions and samples of single blood donors through affinity chromatography. However, besides the fact that this approach provides mere limited amounts of the desired antibody, polyclonal antibodies are of only limited use for therapeutic application, for example because of their heterogeneity and the risk of being contaminated with other α-synuclein associated molecules which have undesired side

effects. Likewise, the diagnostic value of polyclonal antibodies is reduced since the variability of the composition of the antibodies will influence the overall specificity and reactivity. This is all the more true for antibodies against proteins subject of aggregation and deposition due to misfolding.

Thus, there is a need to overcome the above-described limitations and to provide a therapeutic and diagnostic human antibody against α-synuclein.

SUMMARY OF THE INVENTION

The present invention makes use of the α-synuclein-specific immune response of aged healthy control subjects and patients with neurological disease for the isolation of natural α-synuclein specific human monoclonal antibodies. In particular, experiments performed in accordance with the present invention were successful in the isolation of monoclonal antibodies specific for α-synuclein from a pool of elderly subjects with no signs of Parkinsonism.

The present invention is thus directed to human antibodies, antigen-binding fragments and similar antigen-binding molecules which are capable of specifically recognizing α-synuclein. By "specifically recognizing α-synuclein", "antibody specific to/for α-synuclein" and "anti-α-synuclein antibody" is meant specifically, generally, and collectively, antibodies to the native form of α-synuclein, or misfolded or oligomeric or aggregated or posttranslationally modified α-synuclein. Provided herein are human antibodies selective for native monomer, full-length, truncated and aggregated forms.

In a particularly preferred embodiment of the present invention, the human antibody or antigen-binding fragment thereof demonstrates the immunological binding characteristics of an antibody characterized by the variable regions V_H and/or V_L as set forth in Fig. 1.

The antigen-binding fragment of the antibody can be a single chain Fv fragment, an F(ab') fragment, an F(ab) fragment, and an $F(ab')_2$ fragment, or any other antigen-binding fragment. In a specific embodiment, infra, the antibody or fragment thereof is a human IgG isotype antibody. Alternatively, the antibody is a chimeric human-murine or murinized antibody, the latter being particularly useful for diagnostic methods and studies in animals.

Furthermore, the present invention relates to compositions comprising the antibody of the present invention or active fragments thereof, or agonists and cognate molecules, or alternately, antagonists of the same and to immunotherapeutic and immunodiagnostic methods using such compositions in the prevention, diagnosis or treatment of a synucleinopathic disease, wherein an effective amount of the composition is administered to a patient in need thereof.

Naturally, the present invention extends to the immortalized human B memory lymphocyte and B cell, respectively, that produces the antibody having the distinct and unique characteristics as defined below.

The present invention also relates to polynucleotides encoding at least a variable region of an immunoglobulin chain of the antibody of the invention. Preferably, said variable region comprises at least one complementarity determining region (CDR) of the V_H and/or V_L of the variable region as set forth in Figure 1.

Accordingly, the present invention also encompasses vectors comprising said polynucleotides and host cells transformed therewith as well as their use for the production of an antibody and equivalent binding molecules which are specific for α-synuclein. Means and methods for the recombinant production of antibodies and mimics thereof as well as methods of screening for competing binding molecules, which may or may not be antibodies, are known in the art. However, as described herein, in particular with respect to therapeutic applications in human the antibody of the present invention is a human antibody in the sense that application of said antibody is substantially free of a HAMA response otherwise observed for chimeric and even humanized antibodies.

Furthermore, disclosed herein are compositions and methods that can be used to identify α-synuclein in samples. The disclosed anti-α-synuclein antibodies can be used to screen human blood, CSF, and urine for the presence of α-synuclein in samples, for example, by using ELISA-based or surface adapted assay. The methods and compositions disclosed herein can aid in synucleinopathic disease such as Parkinson's disease diagnosis and can be used to monitor disease progression and therapeutic efficacy.

As demonstrated in Example 4, the anti-α-synuclein antibody of the present invention is capable of improving motor performance and elevated plus maze behavior in a transgenic mouse model of Parkinson's disease. These results confirm the expected therapeutic value of the human-derived anti-α-synuclein antibodies of the present invention.

Hence, it is a particular object of the present invention to provide methods for treating or preventing a synucleinopathic disease such as Parkinson's disease (PD), Parkinson's Disease Dementia (PDD), dementia with Lewy bodies (DLB), the Lewy body variant of Alzheimer's disease (LBVAD), multiple systems atrophy (MSA), pure autonomic failure (PAF), neurodegeneration with brain iron accumulation type-1 (NBIA-I), Alzheimer's disease, Pick disease, juvenile-onset generalized neuroaxonal dystrophy (Hallervorden-Spatz disease), amyotrophic lateral sclerosis, traumatic brain injury and Down syndrome. The methods comprise administering an effective concentration of a human antibody or antibody derivative to the subject where the antibody targets α-synuclein.

Further embodiments of the present invention will be apparent from the description and Examples that follow.

BRIEF DESCRIPTION OF THE DRAWINGS

Fig. 1: Amino acid and nucleotide sequences of the variable region, *i.e.* heavy chain and kappa/lambda light chain of human antibodies NI-202.3G12 (A), NI-202.12F4 (B) and NI-202.3D8 (C). For human antibody NI-202.3D8 two variable light chain sequences VKa1 (C) and VKc1 (D) have been cloned, each of which may be paired with the variable heavy chain sequence VHE1 (C). Framework (FR) and complementarity determining regions (CDRs) are indicated with the CDRs being underlined. The heavy chain joining region (JH) and light chain joining region (JK) are indicated as well. Due to the cloning strategy the amino acid sequence at the N-terminus of the heavy chain and light chain may potentially contain primer-induced alterations in FR1, which however do not substantially affect the biological activity of the antibody. In order to provide a consensus human antibody, the nucleotide and amino acid sequences of the original clone were aligned with and tuned in accordance with the pertinent human germ line

variable region sequences in the database; see, *e.g.*, Vbase (http://vbase.mrc-cpe.cam.ac.uk/) hosted by the MRC Centre for Protein Engineering (Cambridge, UK). Those amino acids, which are considered to potentially deviate from the consensus germ line sequence and thus could be due to the PCR primer, are indicated in bold.

Fig. 2: Recombinant human α-synuclein antibodies are directed against distinct epitopes. Recombinant full-length and truncated α-synuclein was coated onto ELISA plates at equal coating concentration (20μg/ml). (A) Recombinant human α-synuclein antibody NI-202.3G12 binds to full length α-synuclein but not to α-synuclein truncations in a direct ELISA, pointing to a structural recognition epitope of NI-202.3G12. (B) Recombinant NI-202.12F4 binds to full length α-synuclein and to α-synuclein truncations containing amino acids (aa) 1-60 in a direct ELISA, pointing to an epitope of NI-202.12F4 within the N-terminal amphipathic repeat region of alpha synuclein. (C) LB509 antibody binds to C-terminal α-synuclein fragments confirming the previously determined epitope (aa 115-122). Values are means ± SEM (n=2-3).

Fig. 3: Recombinant human α-synuclein antibodies bind α-synuclein but not β- and γ-synuclein in a direct ELISA. Recombinant α-, β- and γ-synuclein coated onto ELISA plates at equal coating concentration (2μg/ml) were incubated with recombinant human α-synuclein antibodies or with a pan synuclein antibody. (A) The latter detects all three synuclein proteins whereas recombinant human α-synuclein antibodies (B) NI-202.3G12 and (C) NI-202.12F4 (C) selectively bind to α-synuclein. Values are means ± SEM (n=2-3).

Fig. 4: Recombinant human α-synuclein antibody NI-202.12F4 binds α-synuclein but not β- and γ-synuclein on Western blot analysis. Recombinant α-, β- and γ-synuclein (each 750 ng) were subjected to SDS-PAGE and subsequent to Western Blot analysis. (A) Coomassie staining reveals equal protein concentration on SDS-PAGE. (B) NI-202.12F4 strongly interacts with α-synuclein but not with beta or gamma synuclein. (C) No signal was detected without primary antibody.

Fig. 5: (A) NI-202.12F4 immunoblot analysis of brain extracts from non-transgenic and human alpha-synuclein transgenic mice shows preferential binding to human α-synuclein. Brain extracts from wild type and human α-synuclein transgenic mice were analyzed by immunoblotting with human specific α-synuclein antibody LB509, human and mouse α-synuclein reactive antibody clone 42 and NI-202.12F4. While clone 42 detects prominent bands corresponding to mouse and human α-synuclein, LB509 and NI-202.12F4 show a strong preference for human α-synuclein. (B) NI-202.12F4 immunoblot analysis of brain extracts shows preferential binding to human α-synuclein aggregates. Cortical brain extracts from a healthy control subject and a dementia with Lewy bodies (DLB) patient as well as brain extracts from wild type mice and human A30P α-synuclein transgenic mice were analyzed by Western blotting. NI-202.12F4 detects oligomeric and fibrillar forms of α-synuclein aggregates in DLB and A30P α-synuclein transgenic brain extract with high sensitivity. Minimal binding is observed to monomeric forms of α-synuclein in human or wild type mouse tissues and moderate binding in A30P α-synuclein transgenic brain extracts highly overexpressing α-synuclein. In contrast, clone 42 antibody detects monomeric forms and α-synuclein fragments with a high sensitivity and poorly binds to aggregated α-synuclein species.

Fig. 6: Recombinant NI-202.12F4 shows high affinity binding to wild type and disease causing mutants of human α-synuclein. Recombinant wild-type (•), A53T (■), A30P (*) and E64K (◊) human α-synuclein were coated on ELISA plates (2 µg/ml) and probed with various concentrations of NI202.12F4. Half maximal effective concentrations (EC50) were 321pM for wild-type α-synuclein, 293pM for A53T, 228pM for A30P and 483pM for E64K mutant human α-synuclein.

Fig. 7: Immunohistochemical binding analysis of NI-202.12F4. NI-202.12F4 shows prominent staining of α-synuclein pathology including Lewy body and Lewy neurite like inclusion as well as small somatodendritic and synaptic α-synuclein accumulations in free-floating sections from transgenic mice expressing human A53T (A) or A30P α-synuclein (B) as well as in human brain tissues of

Parkinson's disease (C) and dementia with Lewy bodies (D). Antibody Syn211 detects physiological synaptic α-synuclein with a high sensitivity in human A30P α-synuclein transgenic mice (E) while NI-202.12F4 binds preferentially to pathological α-synuclein aggregates (B). Binding of NI-202.12F4 is virtually absent from brain sections of wild type mice (F) comparable to secondary antibody only control staining (G) while clone 42 antibody shows prominent synaptic staining of mouse α-synuclein protein (H).

Fig. 8: Recombinant NI-202.12F4 shows preferential binding to high density coated α-synuclein.. Recombinant full-length or truncated α-synuclein were coated on ELISA plates at the indicated concentrations and probed with various concentrations of NI-202.12F4 or Syn211 antibodies by direct ELISA (O20 µg/ml; ▲ 2 µg/ml; ▼ 1 µg/ml; ◆ 250 ng/ml; □ 100 ng/ml coating concentration of recombinant full length or 1-60 α-synuclein). The half maximal effective concentration (EC50) indicating the potency of the antibodies was determined. (A) High affinity binding of recombinant NI-202.12F4 to α-synuclein requires high coating densities of α-synuclein protein. While a 111 pM EC50 is observed for α-synuclein coated at 20 µg/ml concentration EC50 values increase sharply with decreasing coating concentrations demonstrating a dramatic loss in affinity at lower coating concentrations of α-synuclein. These features are pointing to a conformational epitope of NI-202.12F4 that is preferentially formed at high coating concentrations of α-synuclein. (B) Binding of Syn211 is not affected by the coating concentration. No decrease in affinity is observed of the commercially available Syn211 antibody at lower coating densities with EC50s ranging from 335 pm for 20 µg/ml to 99 pM for 100 ng/ml coating density of α-synuclein, suggesting binding to a linear non-conformational epitope. (C) High affinity binding of recombinant NI-202.12F4 to N-terminal α-synuclein fragment comprising amino acids 1-60 requires high coating densities. NI-202.12F4 shows equivalent and coating concentration dependent binding to full-length as well as truncatedα-synuclein pointing to a conformational epitope of NI-202.12F4 that is contained within amino acids 1-60 of the α-synuclein protein. (D) Biotinylated peptides comprising overlapping 20 amino acid fragments covering the N-terminal 60 amino acids of α-synuclein

were coated on avidin plates and probed with NI-202.12F4 or a pan-synuclein control antibody that detects an epitope within aa 21-40. Accordingly, the control antibody strongly binds peptide 21-40 and to lesser extent peptides 11-30 and 31-50. In contrast, no binding is observed for NI-202.12F4 to any of the peptides tested, suggesting that none of the N-terminal fragments is sufficient as NI-202.12F4 epitope and a larger fragment may be required for optimal binding and formation of the structural NI-202.12F4 epitope.

Fig. 9: Chronic treatment with NI-202.12F4 improves motor performance in α-synuclein A53T transgenic mice. 10.5 month old α-synuclein A53T transgenic mice were treated weekly with NI-202.12F4 or PBS (5mg/kg; intraperitoneal application). Motor performance was assessed after two months of treatment in the Pole-Test. (A) NI-202.12F4 treated animals required significantly less time to turn downwards (t-turn; 1.7 ± 0.3 vs. 4.6 ± 0.6 sec, p=0.0002, two-tailed Student's t-test). (B) NI-202.12F4 treated animals also used significantly less time (t-total) to descend to the home cage (7.3 ± 0.9 vs. 10.4 ± 0.7 sec, p=0.012, two-tailed Student's t-test).

Fig. 10: Chronic treatment of α-synuclein A53T transgenic mice with NI-202.12F4 leads to recovery of elevated plus maze behavior. 10.5 month old α-synuclein A53T transgenic mice were treated weekly i.p. with 5 mg/kg NI-202.12F4 or PBS. After two month of treatment, animals were tested for elevated plus maze behavior. NI-202.12F4 treated animals spend significantly less time and covered significantly lower distance in the open arms compared to vehicle treated control animals indicating a recovery of normal behavior.

Fig. 11: Chronic treatment of α-synuclein A53T transgenic mice with NI-202.12F4 results in elevated plasma levels of human A53T α-synuclein. Plasma samples were prepared from 12.5 month old α-synuclein A53T transgenic mice that had been treated weekly i.p. for 2 months with 5mg/kg NI-202.12F4 or PBS. Blood was taken 24 hrs after last application. (A) NI-202.12F4 levels in plasma were determined using a direct α-synuclein ELISA. (B) Human A53T α-synuclein levels in plasma were determined using a human-specific α-synuclein sandwich

ELISA. Animals treated with NI-202.12F4 have significantly elevated levels of human α-synuclein in plasma compared to control animals (24.9 ± 4.1 vs. 1.9 ± 1.2 ng/ml, p=0.0002).

DETAILED DESCRIPTION OF THE INVENTION

I. Definitions

Synucleinopathic diseases or synucleinopathies are a diverse group of neurodegenerative disorders that share a common pathologic lesion composed of aggregates of insoluble α-synuclein protein in selectively vulnerable populations of neurons and glia. These disorders include Parkinson's disease (PD), Parkinson's Disease Dementia (PDD), dementia with Lewy bodies (DLB), juvenile-onset generalized neuroaxonal dystrophy (Hallervorden-Spatz disease), pure autonomic failure (PAF), multiple system atrophy (MSA) and neurodegeneration with brain iron accumulation type-1 (NBIA-I). Clinically, they are characterized by a chronic and progressive decline in motor, cognitive, behavioral, and autonomic functions, depending on the distribution of the lesions.

Parkinson's disease is an age-dependent neurodegenerative disease with unknown etiology. It is believed that sporadic Parkinson's disease results from a combination of genetic vulnerability and environmental insults. It is further believed that Parkinson's disease (PD) while triggered by disparate mechanisms follows a shared pathophysiologic pathway. One shared node is the involvement of α-synuclein. Linkage of this protein with Parkinson's disease pathogenesis has been established by the identification of both point mutations and triplication of the gene in familial cases, the localization of α-synuclein to Lewy bodies, one of the hallmark pathological features of Parkinson's disease, and the correlation of α-synuclein expression and disease pathology in neurotoxic models of Parkinson's disease. Further evidence indicates that particular forms of α-synuclein (*e.g.*, misfolded and α-synuclein bonded dopamine) are involved in sporadic disease.

Synucleins are small, soluble proteins expressed primarily in neural tissue and in certain tumors. The family includes three known proteins: α-synuclein, β-synuclein, and γ-synuclein. All synucleins have in common a highly conserved α-helical lipid-binding motif with similarity to the class-A2 lipid-binding domains of the exchangeable apolipoproteins. Synuclein family members are not found outside vertebrates, although they have some conserved structural similarity with plant 'late-embryo-abundant' proteins. The α- and β-synuclein proteins are found primarily in brain tissue, where they are seen mainly in

presynaptic terminals. The γ-synuclein protein is found primarily in the peripheral nervous system and retina, but its expression in breast tumors is a marker for tumor progression. Normal cellular functions have not been determined for any of the synuclein proteins, although some data suggest a role in the regulation of membrane stability and/or turnover. Mutations in α-synuclein are associated with rare familial cases of early-onset Parkinson's disease, and the protein accumulates abnormally in Parkinson's disease, Alzheimer's disease, and several other neurodegenerative illnesses. For review see, *e.g.*, George, Genome Biol. 3 (2002), reviews3002.1–reviews3002.6 published online December 20, 2001, in which Table 1 catalogs the unique members of the synuclein family that are currently listed in GenBank, the disclosure content of which is incorporated herein by reference.

α-synuclein was originally identified in human brains as the precursor protein of the non-β-amyloid component of (NAC) of Alzheimer's disease (AD) plaques; *see, e.g.*, Ueda *et al*, Proc. Natl. Acad. Sci. U.S.A. 90 (1993), 1282-1286. α-synuclein, also termed the precursor of the non-Aβ component of AD amyloid (NACP), is a protein of 140 amino acids. α-synuclein exists in its native form as a random coil; however, changes in pH, molecular crowding, heavy metal content, and dopamine levels all affect protein conformation. Changes in conformation to oligomeric, proto-fibrillar, fibrillar, and aggregate moieties are thought to regulate protein toxicity. Increasing evidence indicates that dopamine-adducted α-synuclein has a faster time course to fibril formation compared to non-adducted protein. Furthermore, dopamine in the background of α-synuclein overexpression is toxic.

In this specification, the terms "α-synuclein", "alpha-synuclein", "a-synuclein" and "aSyn" are used interchangeable to specifically refer to the native monomer form of α-synuclein. The term "α-synuclein" is also used to generally identify other conformers of α-synuclein, for example, α-synuclein bonded to dopamine-quinone (DAQ) and oligomers or aggregates of α-synuclein. The term "α-synuclein" is also used to refer collectively to all types and forms of α-synuclein. The protein sequence for human α-synuclein is MDVFMKGLSKAKEGVVAAAEKTKQGVAEAAGKTKEGVLYVGSKTKEGVVHGVAT VAEKTKEQVTNVGGAVVTGVTAVAQKTVEGAGSIAAATGFVKKDQLGKNEEGAPQ EGILEDMPVDPDNEAYEMPSEEGYQDYEPEA (SEQ ID NO: 1). The amino acid sequence of α-synuclein can be retrieved from the literature and pertinent databases; see, *e.g.*, Ueda *et al.*, *ibid.*; GenBank swissprot: locus SYUA_HUMAN, accession number P37840.

The non-Aβ component of AD amyloid (NAC) is derived from α-synuclein. NAC, a highly hydrophobic domain within α-synuclein, is a peptide consisting of at least 28 amino acids residues (residues 60-87) and optionally 35 amino acid residues (residues 61-95). NAC displays a tendency to form a beta-sheet structure (Iwai, *et al.*, Biochemistry, 34 (1995) 10139-10145). The amino acid sequences of NAC are described in Jensen *et al.*, Biochem. J. 310 (1995), 91-94; GenBank accession number S56746 and Ueda *et al.*, PNAS USA 90 (1993), 1282-11286.

Disaggregated α-synuclein or fragments thereof, including NAC, means monomeric peptide units. Disaggregated α-synuclein or fragments thereof are generally soluble, and are capable of self-aggregating to form soluble oligomers. Oligomers of α-synuclein and fragments thereof are usually soluble and exist predominantly as α-helices. Monomeric α-synuclein may be prepared *in vitro* by dissolving lyophilized peptide in neat DMSO with sonication. The resulting solution is centrifuged to remove any insoluble particulates. Aggregated α-synuclein or fragments thereof, including NAC, means oligomers of α-synuclein or fragments thereof which have associate into insoluble β-sheet assemblies. Aggregated α-synuclein or fragments thereof, including NAC, means also means fibrillar polymers. Fibrils are usually insoluble. Some antibodies bind either soluble α-synuclein or fragments thereof or aggregated α-synuclein or fragments thereof. Some antibodies bind to oligomers of α-synuclein more strongly than to monomeric forms or fibrillar forms. Some antibodies bind both soluble and aggregated α-synuclein or fragments thereof, and optionally oligomeric forms as well.

The human anti-α-synuclein antibodies disclosed herein specifically bind α-synuclein and epitopes thereof and to various conformations of α-synuclein and epitopes thereof. For example, disclosed herein are antibodies that specifically bind α-synuclein, α-synuclein in its native monomer form, full-length and truncated α-synuclein and α-synuclein aggregates. As used herein, reference to an antibody that "specifically binds", "selectively binds", or "preferentially binds" α-synuclein refers to an antibody that does not bind other unrelated proteins. In one example, an α-synuclein antibody disclosed herein can bind α-synuclein or an epitope thereof and show no binding above about 1.5 times background for other proteins. An antibody that "specifically binds" or "selectively binds" α-synuclein conformer refers to an antibody that does not bind all conformations of α-synuclein, *i.e.*, does not bind at least one other α-synuclein conformer. For example, disclosed herein are antibodies that can distinguish

among monomeric and aggregated forms of α-synuclein, human and mouse α-synuclein; full-length α-synuclein and truncated forms as well as human α-synuclein versus β- and γ-synuclein. Since the human anti-α-synuclein antibodies of the present invention have been isolated from a pool of elderly subjects with no signs of Parkinsonism and exhibiting an α-synuclein-specific immune response the anti-α-synuclein antibodies of the present invention may also be called "human auto-antibodies" in order to emphasize that those antibodies were indeed expressed by the subjects and have not been isolated from, for example a human immunoglobulin expressing phage library, which hitherto represented one common method for trying to provide human-like antibodies.

It is to be noted that the term "a" or "an" entity refers to one or more of that entity; for example, "an antibody," is understood to represent one or more antibodies. As such, the terms "a" (or "an"), "one or more," and "at least one" can be used interchangeably herein.

As used herein, the term "polypeptide" is intended to encompass a singular "polypeptide" as well as plural "polypeptides," and refers to a molecule composed of monomers (amino acids) linearly linked by amide bonds (also known as peptide bonds). The term "polypeptide" refers to any chain or chains of two or more amino acids, and does not refer to a specific length of the product. Thus, peptides, dipeptides, tripeptides, oligopeptides, "protein," "amino acid chain," or any other term used to refer to a chain or chains of two or more amino acids, are included within the definition of "polypeptide," and the term "polypeptide" may be used instead of, or interchangeably with any of these terms.

The term "polypeptide" is also intended to refer to the products of post-expression modifications of the polypeptide, including without limitation glycosylation, acetylation, phosphorylation, amidation, derivatization by known protecting/blocking groups, proteolytic cleavage, or modification by non-naturally occurring amino acids. A polypeptide may be derived from a natural biological source or produced by recombinant technology, but is not necessarily translated from a designated nucleic acid sequence. It may be generated in any manner, including by chemical synthesis.

A polypeptide of the invention may be of a size of about 3 or more, 5 or more, 10 or more, 20 or more, 25 or more, 50 or more, 75 or more, 100 or more, 200 or more, 500 or more, 1,000

or more, or 2,000 or more amino acids. Polypeptides may have a defined three-dimensional structure, although they do not necessarily have such structure. Polypeptides with a defined three-dimensional structure are referred to as folded, and polypeptides which do not possess a defined three-dimensional structure, but rather can adopt a large number of different conformations, and are referred to as unfolded. As used herein, the term glycoprotein refers to a protein coupled to at least one carbohydrate moiety that is attached to the protein via an oxygen-containing or a nitrogen-containing side chain of an amino acid residue, *e.g.*, a serine residue or an asparagine residue.

By an "isolated" polypeptide or a fragment, variant, or derivative thereof is intended a polypeptide that is not in its natural milieu. No particular level of purification is required. For example, an isolated polypeptide can be removed from its native or natural environment. Recombinantly produced polypeptides and proteins expressed in host cells are considered isolated for purposed of the invention, as are native or recombinant polypeptides which have been separated, fractionated, or partially or substantially purified by any suitable technique.

Also included as polypeptides of the present invention are fragments, derivatives, analogs, or variants of the foregoing polypeptides, and any combination thereof. The terms "fragment," "variant," "derivative" and "analog" when referring to antibodies or antibody polypeptides of the present invention include any polypeptides which retain at least some of the antigen-binding properties of the corresponding native binding molecule, antibody, or polypeptide. Fragments of polypeptides of the present invention include proteolytic fragments, as well as deletion fragments, in addition to specific antibody fragments discussed elsewhere herein. Variants of antibodies and antibody polypeptides of the present invention include fragments as described above, and also polypeptides with altered amino acid sequences due to amino acid substitutions, deletions, or insertions. Variants may occur naturally or be non-naturally occurring. Non-naturally occurring variants may be produced using art-known mutagenesis techniques. Variant polypeptides may comprise conservative or non-conservative amino acid substitutions, deletions or additions. Derivatives of α-synuclein specific binding molecules, *e.g.*, antibodies and antibody polypeptides of the present invention, are polypeptides which have been altered so as to exhibit additional features not found on the native polypeptide. Examples include fusion proteins. Variant polypeptides may also be referred to herein as "polypeptide analogs". As used herein a "derivative" of a binding molecule or fragment

thereof, an antibody, or an antibody polypeptide refers to a subject polypeptide having one or more residues chemically derivatized by reaction of a functional side group. Also included as "derivatives" are those peptides which contain one or more naturally occurring amino acid derivatives of the twenty standard amino acids. For example, 4-hydroxyproline may be substituted for proline; 5-hydroxylysine may be substituted for lysine; 3-methylhistidine may be substituted for histidine; homoserine may be substituted for serine; and ornithine may be substituted for lysine.

The term "polynucleotide" is intended to encompass a singular nucleic acid as well as plural nucleic acids, and refers to an isolated nucleic acid molecule or construct, *e.g.*, messenger RNA (mRNA) or plasmid DNA (pDNA). A polynucleotide may comprise a conventional phosphodiester bond or a non-conventional bond (*e.g.*, an amide bond, such as found in peptide nucleic acids (PNA)). The term "nucleic acid" refers to any one or more nucleic acid segments, *e.g.*, DNA or RNA fragments, present in a polynucleotide. By "isolated" nucleic acid or polynucleotide is intended a nucleic acid molecule, DNA or RNA, which has been removed from its native environment. For example, a recombinant polynucleotide encoding an antibody contained in a vector is considered isolated for the purposes of the present invention. Further examples of an isolated polynucleotide include recombinant polynucleotides maintained in heterologous host cells or purified (partially or substantially) polynucleotides in solution. Isolated RNA molecules include *in vivo* or *in vitro* RNA transcripts of polynucleotides of the present invention. Isolated polynucleotides or nucleic acids according to the present invention further include such molecules produced synthetically. In addition, polynucleotide or a nucleic acid may be or may include a regulatory element such as a promoter, ribosome binding site, or a transcription terminator.

As used herein, a "coding region" is a portion of nucleic acid which consists of codons translated into amino acids. Although a "stop codon" (TAG, TGA, or TAA) is not translated into an amino acid, it may be considered to be part of a coding region, but any flanking sequences, for example promoters, ribosome binding sites, transcriptional terminators, introns, and the like, are not part of a coding region. Two or more coding regions of the present invention can be present in a single polynucleotide construct, *e.g.*, on a single vector, or in separate polynucleotide constructs, *e.g.*, on separate (different) vectors. Furthermore, any vector may contain a single coding region, or may comprise two or more coding regions, *e.g.*,

a single vector may separately encode an immunoglobulin heavy chain variable region and an immunoglobulin light chain variable region. In addition, a vector, polynucleotide, or nucleic acid of the invention may encode heterologous coding regions, either fused or unfused to a nucleic acid encoding a binding molecule, an antibody, or fragment, variant, or derivative thereof. Heterologous coding regions include without limitation specialized elements or motifs, such as a secretory signal peptide or a heterologous functional domain.

In certain embodiments, the polynucleotide or nucleic acid is DNA. In the case of DNA, a polynucleotide comprising a nucleic acid which encodes a polypeptide normally may include a promoter and/or other transcription or translation control elements operably associated with one or more coding regions. An operable association is when a coding region for a gene product, *e.g.*, a polypeptide, is associated with one or more regulatory sequences in such a way as to place expression of the gene product under the influence or control of the regulatory sequence(s). Two DNA fragments (such as a polypeptide coding region and a promoter associated therewith) are "operably associated" or "operably linked" if induction of promoter function results in the transcription of mRNA encoding the desired gene product and if the nature of the linkage between the two DNA fragments does not interfere with the ability of the expression regulatory sequences to direct the expression of the gene product or interfere with the ability of the DNA template to be transcribed. Thus, a promoter region would be operably associated with a nucleic acid encoding a polypeptide if the promoter was capable of effecting transcription of that nucleic acid. The promoter may be a cell-specific promoter that directs substantial transcription of the DNA only in predetermined cells. Other transcription control elements, besides a promoter, for example enhancers, operators, repressors, and transcription termination signals, can be operably associated with the polynucleotide to direct cell-specific transcription. Suitable promoters and other transcription control regions are disclosed herein.

A variety of transcription control regions are known to those skilled in the art. These include, without limitation, transcription control regions which function in vertebrate cells, such as, but not limited to, promoter and enhancer segments from cytomegaloviruses (the immediate early promoter, in conjunction with intron-A), simian virus 40 (the early promoter), and retroviruses (such as Rous sarcoma virus). Other transcription control regions include those derived from vertebrate genes such as actin, heat shock protein, bovine growth hormone and

rabbit ß-globin, as well as other sequences capable of controlling gene expression in eukaryotic cells. Additional suitable transcription control regions include tissue-specific promoters and enhancers as well as lymphokine-inducible promoters (*e.g.*, promoters inducible by interferons or interleukins).

Similarly, a variety of translation control elements are known to those of ordinary skill in the art. These include, but are not limited to ribosome binding sites, translation initiation and termination codons, and elements derived from picornaviruses (particularly an internal ribosome entry site, or IRES, also referred to as a CITE sequence).

In other embodiments, a polynucleotide of the present invention is RNA, for example, in the form of messenger RNA (mRNA).

Polynucleotide and nucleic acid coding regions of the present invention may be associated with additional coding regions which encode secretory or signal peptides, which direct the secretion of a polypeptide encoded by a polynucleotide of the present invention. According to the signal hypothesis, proteins secreted by mammalian cells have a signal peptide or secretory leader sequence which is cleaved from the mature protein once export of the growing protein chain across the rough endoplasmic reticulum has been initiated. Those of ordinary skill in the art are aware that polypeptides secreted by vertebrate cells generally have a signal peptide fused to the N-terminus of the polypeptide, which is cleaved from the complete or "full length" polypeptide to produce a secreted or "mature" form of the polypeptide. In certain embodiments, the native signal peptide, *e.g.*, an immunoglobulin heavy chain or light chain signal peptide is used, or a functional derivative of that sequence that retains the ability to direct the secretion of the polypeptide that is operably associated with it. Alternatively, a heterologous mammalian signal peptide, or a functional derivative thereof, may be used. For example, the wild-type leader sequence may be substituted with the leader sequence of human tissue plasminogen activator (TPA) or mouse ß-glucuronidase.

Unless stated otherwise, the terms "disorder" and "disease" are used interchangeably herein.

A "binding molecule" as used in the context of the present invention relates primarily to antibodies, and fragments thereof, but may also refer to other non-antibody molecules that

bind to α-synuclein including but not limited to hormones, receptors, ligands, major histocompatibility complex (MHC) molecules, chaperones such as heat shock proteins (HSPs) as well as cell-cell adhesion molecules such as members of the cadherin, intergrin, C-type lectin and immunoglobulin (Ig) superfamilies. Thus, for the sake of clarity only and without restricting the scope of the present invention most of the following embodiments are discussed with respect to antibodies and antibody-like molecules which represent the preferred binding molecules for the development of therapeutic and diagnostic agents.

The terms "antibody" and "immunoglobulin" are used interchangeably herein. An antibody or immunoglobulin is an α-synuclein-binding molecule which comprises at least the variable domain of a heavy chain, and normally comprises at least the variable domains of a heavy chain and a light chain. Basic immunoglobulin structures in vertebrate systems are relatively well understood; see, *e.g.*, Harlow *et al.*, Antibodies: A Laboratory Manual, (Cold Spring Harbor Laboratory Press, 2nd ed. 1988).

As will be discussed in more detail below, the term "immunoglobulin" comprises various broad classes of polypeptides that can be distinguished biochemically. Those skilled in the art will appreciate that heavy chains are classified as gamma, mu, alpha, delta, or epsilon, (γ, μ, α, δ, ε) with some subclasses among them (*e.g.*, γ1-γ4). It is the nature of this chain that determines the "class" of the antibody as IgG, IgM, IgA IgG, or IgE, respectively. The immunoglobulin subclasses (isotypes) *e.g.*, IgG1, IgG2, IgG3, IgG4, IgA1, etc. are well characterized and are known to confer functional specialization. Modified versions of each of these classes and isotypes are readily discernable to the skilled artisan in view of the instant disclosure and, accordingly, are within the scope of the instant invention. All immunoglobulin classes are clearly within the scope of the present invention, the following discussion will generally be directed to the IgG class of immunoglobulin molecules. With regard to IgG, a standard immunoglobulin molecule comprises two identical light chain polypeptides of molecular weight approximately 23,000 Daltons, and two identical heavy chain polypeptides of molecular weight 53,000-70,000. The four chains are typically joined by disulfide bonds in a "Y" configuration wherein the light chains bracket the heavy chains starting at the mouth of the "Y" and continuing through the variable region.

Light chains are classified as either kappa or lambda (κ, λ). Each heavy chain class may be bound with either a kappa or lambda light chain. In general, the light and heavy chains are covalently bonded to each other, and the "tail" portions of the two heavy chains are bonded to each other by covalent disulfide linkages or non-covalent linkages when the immunoglobulins are generated either by hybridomas, B cells or genetically engineered host cells. In the heavy chain, the amino acid sequences run from an N-terminus at the forked ends of the Y configuration to the C-terminus at the bottom of each chain.

Both the light and heavy chains are divided into regions of structural and functional homology. The terms "constant" and "variable" are used functionally. In this regard, it will be appreciated that the variable domains of both the light (V_L) and heavy (V_H) chain portions determine antigen recognition and specificity. Conversely, the constant domains of the light chain (CL) and the heavy chain (CH1, CH2 or CH3) confer important biological properties such as secretion, transplacental mobility, Fc receptor binding, complement binding, and the like. By convention the numbering of the constant region domains increases as they become more distal from the antigen-binding site or amino-terminus of the antibody. The N-terminal portion is a variable region and at the C-terminal portion is a constant region; the CH3 and CL domains actually comprise the carboxy-terminus of the heavy and light chain, respectively.

As indicated above, the variable region allows the antibody to selectively recognize and specifically bind epitopes on antigens. That is, the V_L domain and V_H domain, or subset of the complementarity determining regions (CDRs), of an antibody combine to form the variable region that defines a three dimensional antigen-binding site. This quaternary antibody structure forms the antigen-binding site present at the end of each arm of the Y. More specifically, the antigen-binding site is defined by three CDRs on each of the V_H and V_L chains. Any antibody or immunoglobulin fragment which contains sufficient structure to specifically bind to α-synuclein is denoted herein interchangeably as a "binding fragment" or an "immunospecific fragment."

In naturally occurring antibodies, an antibody comprises six hypervariable regions, sometimes called "complementarity determining regions" or "CDRs" present in each antigen-binding domain, which are short, non-contiguous sequences of amino acids that are specifically positioned to form the antigen-binding domain as the antibody assumes its three dimensional

configuration in an aqueous environment. The "CDRs" are flanked by four relatively conserved "framework" regions or "FRs" which show less inter-molecular variability. The framework regions largely adopt a β-sheet conformation and the CDRs form loops which connect, and in some cases form part of, the β-sheet structure. Thus, framework regions act to form a scaffold that provides for positioning the CDRs in correct orientation by inter-chain, non-covalent interactions. The antigen-binding domain formed by the positioned CDRs defines a surface complementary to the epitope on the immunoreactive antigen. This complementary surface promotes the non-covalent binding of the antibody to its cognate epitope. The amino acids comprising the CDRs and the framework regions, respectively, can be readily identified for any given heavy or light chain variable region by one of ordinary skill in the art, since they have been precisely defined; see, "Sequences of Proteins of Immunological Interest," Kabat, E., *et al.*, U.S. Department of Health and Human Services, (1983); and Chothia and Lesk, J. Mol. Biol., 196 (1987), 901-917, which are incorporated herein by reference in their entireties.

In the case where there are two or more definitions of a term which is used and/or accepted within the art, the definition of the term as used herein is intended to include all such meanings unless explicitly stated to the contrary. A specific example is the use of the term "complementarity determining region" ("CDR") to describe the non-contiguous antigen combining sites found within the variable region of both heavy and light chain polypeptides. This particular region has been described by Kabat *et al.*, U.S. Dept. of Health and Human Services, "Sequences of Proteins of Immunological Interest" (1983) and by Chothia and Lesk, J. Mol. Biol., 196 (1987), 901-917, which are incorporated herein by reference, where the definitions include overlapping or subsets of amino acid residues when compared against each other. Nevertheless, application of either definition to refer to a CDR of an antibody or variants thereof is intended to be within the scope of the term as defined and used herein. The appropriate amino acid residues which encompass the CDRs as defined by each of the above cited references are set forth below in Table 1 as a comparison. The exact residue numbers which encompass a particular CDR will vary depending on the sequence and size of the CDR. Those skilled in the art can routinely determine which residues comprise a particular hypervariable region or CDR of the human IgG subtype of antibody given the variable region amino acid sequence of the antibody.

Table 1: CDR Definitions[1]

	Kabat	Chothia
VH CDR1	31-35	26-32
VH CDR2	50-65	52-58
VH CDR3	95-102	95-102
VL CDR1	24-34	26-32
VL CDR2	50-56	50-52
VL CDR3	89-97	91-96

[1]Numbering of all CDR definitions in Table 1 is according to the numbering conventions set forth by Kabat *et al.* (see below).

Kabat *et al.* also defined a numbering system for variable domain sequences that is applicable to any antibody. One of ordinary skill in the art can unambiguously assign this system of "Kabat numbering" to any variable domain sequence, without reliance on any experimental data beyond the sequence itself. As used herein, "Kabat numbering" refers to the numbering system set forth by Kabat *et al.*, U.S. Dept. of Health and Human Services, "Sequence of Proteins of Immunological Interest" (1983). Unless otherwise specified, references to the numbering of specific amino acid residue positions in an antibody or antigen-binding fragment, variant, or derivative thereof of the present invention are according to the Kabat numbering system.

Antibodies or antigen-binding fragments, immunospecific fragments, variants, or derivatives thereof of the invention include, but are not limited to, polyclonal, monoclonal, multispecific, human, humanized, primatized, murinized or chimeric antibodies, single chain antibodies, epitope-binding fragments, *e.g.*, Fab, Fab' and $F(ab')_2$, Fd, Fvs, single-chain Fvs (scFv), single-chain antibodies, disulfide-linked Fvs (sdFv), fragments comprising either a V_L or V_H domain, fragments produced by a Fab expression library, and anti-idiotypic (anti-Id) antibodies (including, *e.g.*, anti-Id antibodies to antibodies disclosed herein). ScFv molecules are known in the art and are described, *e.g.*, in US patent 5,892,019. Immunoglobulin or antibody molecules of the invention can be of any type (*e.g.*, IgG, IgE, IgM, IgD, IgA, and IgY), class (*e.g.*, IgG1, IgG2, IgG3, IgG4, IgA1 and IgA2) or subclass of immunoglobulin molecule.

In one embodiment, the antibody of the present invention is not IgM or a derivative thereof with a pentavalent structure. Particular, in specific applications of the present invention, especially therapeutic use, IgMs are less useful than IgG and other bivalent antibodies or

corresponding binding molecules since IgMs due to their pentavalent structure and lack of affinity maturation often show unspecific cross-reactivities and very low affinity.

In a particularly preferred embodiment, the antibody of the present invention is not a polyclonal antibody, *i.e.* it substantially consists of one particular antibody species rather than being a mixture obtained from a plasma immunoglobulin sample.

Antibody fragments, including single-chain antibodies, may comprise the variable region(s) alone or in combination with the entirety or a portion of the following: hinge region, CH1, CH2, and CH3 domains. Also included in the invention are α-synuclein-binding fragments also comprising any combination of variable region(s) with a hinge region, CH1, CH2, and CH3 domains. Antibodies or immunospecific fragments thereof of the present invention may be from any animal origin including birds and mammals. Preferably, the antibodies are human, murine, donkey, rabbit, goat, guinea pig, camel, llama, horse, or chicken antibodies. In another embodiment, the variable region may be condricthoid in origin (*e.g.*, from sharks).

In one aspect, the antibody of the present invention is a human monoclonal antibody isolated from a human. Optionally, the framework region of the human antibody is aligned and adopted in accordance with the pertinent human germ line variable region sequences in the database; see, *e.g.*, Vbase (http://vbase.mrc-cpe.cam.ac.uk/) hosted by the MRC Centre for Protein Engineering (Cambridge, UK). For example, amino acids considered to potentially deviate from the true germ line sequence could be due to the PCR primer sequences incorporated during the cloning process. Compared to artificially generated human-like antibodies such as single chain antibody fragments (scFvs) from a phage displayed antibody library or xenogeneic mice the human monoclonal antibody of the present invention is characterized by (i) being obtained using the human immune response rather than that of animal surrogates, *i.e.* the antibody has been generated in response to natural α-synuclein in its relevant conformation in the human body, (ii) having protected the individual or is at least significant for the presence of α-synuclein, and (iii) since the antibody is of human origin the risks of cross-reactivity against self-antigens is minimized. Thus, in accordance with the present invention the terms "human monoclonal antibody", "human monoclonal autoantibody", "human antibody" and the like are used to denote an α-synuclein binding molecule which is of human origin, *i.e.* which has been isolated from a human cell such as a

B cell or hybridoma thereof or the cDNA of which has been directly cloned from mRNA of a human cell, for example a human memory B cell. A human antibody is still "human" even if amino acid substitutions are made in the antibody, *e.g.*, to improve binding characteristics.

Antibodies derived from human immunoglobulin libraries or from animals transgenic for one or more human immunoglobulins and that do not express endogenous immunoglobulins, as described *infra* and, for example in, US patent no 5,939,598 by Kucherlapati *et al.*, are denoted human-like antibodies in order distinguish them from truly human antibodies of the present invention.

As used herein, the term "murinized antibody" or "murinized immunoglobulin" refers to an antibody comprising one or more CDRs from a human antibody of the present invention; and a human framework region that contains amino acid substitutions and/or deletions and/or insertions that are based on a mouse antibody sequence. The human immunoglobulin providing the CDRs is called the "parent" or "acceptor" and the mouse antibody providing the framework changes is called the "donor". Constant regions need not be present, but if they are, they are usually substantially identical to mouse antibody constant regions, *i.e.* at least about 85- 90%, preferably about 95% or more identical. Hence, in some embodiments, a full length murinized human heavy or light chain immunoglobulin contains a mouse constant region, human CDRs, and a substantially human framework that has a number of "murinizing" amino acid substitutions. Typically, a "murinized antibody" is an antibody comprising a murinized variable light chain and/or a murinized variable heavy chain. For example, a murinized antibody would not encompass a typical chimeric antibody, *e.g.*, because the entire variable region of a chimeric antibody is non-mouse. A modified antibody that has been "murinized" by the process of "murinization" binds to the same antigen as the parent antibody that provides the CDRs and is usually less immunogenic in mice, as compared to the parent antibody.

As used herein, the term "heavy chain portion" includes amino acid sequences derived from an immunoglobulin heavy chain. A polypeptide comprising a heavy chain portion comprises at least one of: a CH1 domain, a hinge (*e.g.*, upper, middle, and/or lower hinge region) domain, a CH2 domain, a CH3 domain, or a variant or fragment thereof. For example, a binding polypeptide for use in the invention may comprise a polypeptide chain comprising a

CH1 domain; a polypeptide chain comprising a CH1 domain, at least a portion of a hinge domain, and a CH2 domain; a polypeptide chain comprising a CH1 domain and a CH3 domain; a polypeptide chain comprising a CH1 domain, at least a portion of a hinge domain, and a CH3 domain, or a polypeptide chain comprising a CH1 domain, at least a portion of a hinge domain, a CH2 domain, and a CH3 domain. In another embodiment, a polypeptide of the invention comprises a polypeptide chain comprising a CH3 domain. Further, a binding polypeptide for use in the invention may lack at least a portion of a CH2 domain (*e.g.*, all or part of a CH2 domain). As set forth above, it will be understood by one of ordinary skill in the art that these domains (*e.g.*, the heavy chain portions) may be modified such that they vary in amino acid sequence from the naturally occurring immunoglobulin molecule.

In certain antibodies, or antigen-binding fragments, variants, or derivatives thereof disclosed herein, the heavy chain portions of one polypeptide chain of a multimer are identical to those on a second polypeptide chain of the multimer. Alternatively, heavy chain portion-containing monomers of the invention are not identical. For example, each monomer may comprise a different target binding site, forming, for example, a bispecific antibody or diabody.

In another embodiment, the antibodies, or antigen-binding fragments, variants, or derivatives thereof disclosed herein are composed of a single polypeptide chain such as scFvs and are to be expressed intracellularly (intrabodies) for potential *in vivo* therapeutic and diagnostic applications.

The heavy chain portions of a binding polypeptide for use in the diagnostic and treatment methods disclosed herein may be derived from different immunoglobulin molecules. For example, a heavy chain portion of a polypeptide may comprise a CH1 domain derived from an IgG1 molecule and a hinge region derived from an IgG3 molecule. In another example, a heavy chain portion can comprise a hinge region derived, in part, from an IgG1 molecule and, in part, from an IgG3 molecule. In another example, a heavy chain portion can comprise a chimeric hinge derived, in part, from an IgG1 molecule and, in part, from an IgG4 molecule.

As used herein, the term "light chain portion" includes amino acid sequences derived from an immunoglobulin light chain. Preferably, the light chain portion comprises at least one of a V_L or CL domain.

The minimum size of a peptide or polypeptide epitope for an antibody is thought to be about four to five amino acids. Peptide or polypeptide epitopes preferably contain at least seven, more preferably at least nine and most preferably between at least about 15 to about 30 amino acids. Since a CDR can recognize an antigenic peptide or polypeptide in its tertiary form, the amino acids comprising an epitope need not be contiguous, and in some cases, may not even be on the same peptide chain. In the present invention, a peptide or polypeptide epitope recognized by antibodies of the present invention contains a sequence of at least 4, at least 5, at least 6, at least 7, more preferably at least 8, at least 9, at least 10, at least 15, at least 20, at least 25, or between about 15 to about 30 contiguous or non-contiguous amino acids of α-synuclein.

By "specifically binding", or "specifically recognizing", used interchangeably herein, it is generally meant that a binding molecule, *e.g.*, an antibody binds to an epitope via its antigen-binding domain, and that the binding entails some complementarity between the antigen-binding domain and the epitope. According to this definition, an antibody is said to "specifically bind" to an epitope when it binds to that epitope, via its antigen-binding domain more readily than it would bind to a random, unrelated epitope. The term "specificity" is used herein to qualify the relative affinity by which a certain antibody binds to a certain epitope. For example, antibody "A" may be deemed to have a higher specificity for a given epitope than antibody "B," or antibody "A" may be said to bind to epitope "C" with a higher specificity than it has for related epitope "D".

Where present, the term "immunological binding characteristics," or other binding characteristics of an antibody with an antigen, in all of its grammatical forms, refers to the specificity, affinity, cross-reactivity, and other binding characteristics of an antibody.

By "preferentially binding", it is meant that the binding molecule, *e.g.*, antibody specifically binds to an epitope more readily than it would bind to a related, similar, homologous, or analogous epitope. Thus, an antibody which "preferentially binds" to a given epitope would more likely bind to that epitope than to a related epitope, even though such an antibody may cross-react with the related epitope.

By way of non-limiting example, a binding molecule, *e.g.*, an antibody may be considered to bind a first epitope preferentially if it binds said first epitope with a dissociation constant (K_D) that is less than the antibody's K_D for the second epitope. In another non-limiting example, an antibody may be considered to bind a first antigen preferentially if it binds the first epitope with an affinity that is at least one order of magnitude less than the antibody's K_D for the second epitope. In another non-limiting example, an antibody may be considered to bind a first epitope preferentially if it binds the first epitope with an affinity that is at least two orders of magnitude less than the antibody's K_D for the second epitope.

In another non-limiting example, a binding molecule, *e.g.*, an antibody may be considered to bind a first epitope preferentially if it binds the first epitope with an off rate (k(off)) that is less than the antibody's k(off) for the second epitope. In another non-limiting example, an antibody may be considered to bind a first epitope preferentially if it binds the first epitope with an affinity that is at least one order of magnitude less than the antibody's k(off) for the second epitope. In another non-limiting example, an antibody may be considered to bind a first epitope preferentially if it binds the first epitope with an affinity that is at least two orders of magnitude less than the antibody's k(off) for the second epitope.

A binding molecule, *e.g.*, an antibody or antigen-binding fragment, variant, or derivative disclosed herein may be said to bind a α-synuclein or a fragment or variant thereof with an off rate (k(off)) of less than or equal to 5×10^{-2} sec^{-1}, 10^{-2} sec^{-1}, 5×10^{-3} sec^{-1} or 10^{-3} sec^{-1}. More preferably, an antibody of the invention may be said to bind α-synuclein or a fragment or variant thereof with an off rate (k(off)) less than or equal to 5×10^{-4} sec^{-1}, 10^{-4} sec^{-1}, 5×10^{-5} sec^{-1}, or 10^{-5} sec^{-1} 5×10^{-6} sec^{-1}, 10^{-6} sec^{-1}, 5×10^{-7} sec^{-1} or 10^{-7} sec^{-1}.

A binding molecule, *e.g.*, an antibody or antigen-binding fragment, variant, or derivative disclosed herein may be said to bind α-synuclein or a fragment or variant thereof with an on rate (k(on)) of greater than or equal to 10^3 M^{-1} sec^{-1}, 5×10^3 M^{-1} sec^{-1}, 10^4 M^{-1} sec^{-1} or 5×10^4 M^{-1} sec^{-1}. More preferably, an antibody of the invention may be said to bind α-synuclein or a fragment or variant thereof with an on rate (k(on)) greater than or equal to 10^5 M^{-1} sec^{-1}, 5×10^5 M^{-1} sec^{-1}, 10^6 M^{-1} sec^{-1}, or 5×10^6 M^{-1} sec^{-1} or 10^7 M^{-1} sec^{-1}.

A binding molecule, *e.g.*, an antibody is said to competitively inhibit binding of a reference antibody to a given epitope if it preferentially binds to that epitope to the extent that it blocks, to some degree, binding of the reference antibody to the epitope. Competitive inhibition may be determined by any method known in the art, for example, competition ELISA assays. An antibody may be said to competitively inhibit binding of the reference antibody to a given epitope by at least 90%, at least 80%, at least 70%, at least 60%, or at least 50%.

As used herein, the term "affinity" refers to a measure of the strength of the binding of an individual epitope with the CDR of a binding molecule, *e.g.*, an immunoglobulin molecule; see, *e.g.*, Harlow *et al.*, Antibodies: A Laboratory Manual, Cold Spring Harbor Laboratory Press, 2nd ed. (1988) at pages 27-28. As used herein, the term "avidity" refers to the overall stability of the complex between a population of immunoglobulins and an antigen, that is, the functional combining strength of an immunoglobulin mixture with the antigen; see, *e.g.*, Harlow at pages 29-34. Avidity is related to both the affinity of individual immunoglobulin molecules in the population with specific epitopes, and also the valencies of the immunoglobulins and the antigen. For example, the interaction between a bivalent monoclonal antibody and an antigen with a highly repeating epitope structure, such as a polymer, would be one of high avidity. The affinity or avidity of an antibody for an antigen can be determined experimentally using any suitable method; see, for example, Berzofsky *et al.*, "Antibody-Antigen Interactions" In *Fundamental Immunology*, Paul, W. E., Ed., Raven Press New York, N Y (1984), Kuby, Janis Immunology, W. H. Freeman and Company New York, N Y (1992), and methods described herein. General techniques for measuring the affinity of an antibody for an antigen include ELISA, RIA, and surface plasmon resonance. The measured affinity of a particular antibody-antigen interaction can vary if measured under different conditions, *e.g.*, salt concentration, pH. Thus, measurements of affinity and other antigen-binding parameters, *e.g.*, K_D, IC_{50}, are preferably made with standardized solutions of antibody and antigen, and a standardized buffer.

Binding molecules, *e.g.*, antibodies or antigen-binding fragments, variants or derivatives thereof of the invention may also be described or specified in terms of their cross-reactivity. As used herein, the term "cross-reactivity" refers to the ability of an antibody, specific for one antigen, to react with a second antigen; a measure of relatedness between two different antigenic substances. Thus, an antibody is cross reactive if it binds to an epitope other than the

one that induced its formation. The cross reactive epitope generally contains many of the same complementary structural features as the inducing epitope, and in some cases, may actually fit better than the original.

For example, certain antibodies have some degree of cross-reactivity, in that they bind related, but non-identical epitopes, *e.g.*, epitopes with at least 95%, at least 90%, at least 85%, at least 80%, at least 75%, at least 70%, at least 65%, at least 60%, at least 55%, and at least 50% identity (as calculated using methods known in the art and described herein) to a reference epitope. An antibody may be said to have little or no cross-reactivity if it does not bind epitopes with less than 95%, less than 90%, less than 85%, less than 80%, less than 75%, less than 70%, less than 65%, less than 60%, less than 55%, and less than 50% identity (as calculated using methods known in the art and described herein) to a reference epitope. An antibody may be deemed "highly specific" for a certain epitope, if it does not bind any other analog, ortholog, or homolog of that epitope.

Binding molecules, *e.g.*, antibodies or antigen-binding fragments, variants or derivatives thereof of the invention may also be described or specified in terms of their binding affinity to α-synuclein. Preferred binding affinities include those with a dissociation constant or Kd less than 5×10^{-2} M, 10^{-2} M, 5×10^{-3} M, 10^{-3} M, 5×10^{-4} M, 10^{-4} M, 5×10^{-5} M, 10^{-5} M, 5×10^{-6} M, 10^{-6} M, 5×10^{-7} M, 10^{-7} M, 5×10^{-8} M, 10^{-8} M, 5×10^{-9} M, 10^{-9} M, 5×10^{-10} M, 10^{-10} M, 5×10^{-11} M, 10^{-11} M, 5×10^{-12} M, 10^{-12} M, 5×10^{-13} M, 10^{-13} M, 5×10^{-14} M, 10^{-14} M, 5×10^{-15} M, or 10^{-15} M.

As previously indicated, the subunit structures and three dimensional configuration of the constant regions of the various immunoglobulin classes are well known. As used herein, the term "V_H domain" includes the amino terminal variable domain of an immunoglobulin heavy chain and the term "CH1 domain" includes the first (most amino terminal) constant region domain of an immunoglobulin heavy chain. The CH1 domain is adjacent to the V_H domain and is amino terminal to the hinge region of an immunoglobulin heavy chain molecule.

As used herein the term "CH2 domain" includes the portion of a heavy chain molecule that extends, *e.g.*, from about residue 244 to residue 360 of an antibody using conventional numbering schemes (residues 244 to 360, Kabat numbering system; and residues 231-340, EU

numbering system; see Kabat EA *et al. op. cit*). The CH2 domain is unique in that it is not closely paired with another domain. Rather, two N-linked branched carbohydrate chains are interposed between the two CH2 domains of an intact native IgG molecule. It is also well documented that the CH3 domain extends from the CH2 domain to the C-terminal of the IgG molecule and comprises approximately 108 residues.

As used herein, the term "hinge region" includes the portion of a heavy chain molecule that joins the CH1 domain to the CH2 domain. This hinge region comprises approximately 25 residues and is flexible, thus allowing the two N-terminal antigen-binding regions to move independently. Hinge regions can be subdivided into three distinct domains: upper, middle, and lower hinge domains; *see* Roux *et al.*, J. Immunol. 161 (1998), 4083.

As used herein the term "disulfide bond" includes the covalent bond formed between two sulfur atoms. The amino acid cysteine comprises a thiol group that can form a disulfide bond or bridge with a second thiol group. In most naturally occurring IgG molecules, the CH1 and CL regions are linked by a disulfide bond and the two heavy chains are linked by two disulfide bonds at positions corresponding to 239 and 242 using the Kabat numbering system (position 226 or 229, EU numbering system).

As used herein, the terms "linked," "fused" or "fusion" are used interchangeably. These terms refer to the joining together of two more elements or components, by whatever means including chemical conjugation or recombinant means. An "in-frame fusion" refers to the joining of two or more polynucleotide open reading frames (ORFs) to form a continuous longer ORF, in a manner that maintains the correct translational reading frame of the original ORFs. Thus, a recombinant fusion protein is a single protein containing two or more segments that correspond to polypeptides encoded by the original ORFs (which segments are not normally so joined in nature). Although the reading frame is thus made continuous throughout the fused segments, the segments may be physically or spatially separated by, for example, in-frame linker sequence. For example, polynucleotides encoding the CDRs of an immunoglobulin variable region may be fused, in-frame, but be separated by a polynucleotide encoding at least one immunoglobulin framework region or additional CDR regions, as long as the "fused" CDRs are co-translated as part of a continuous polypeptide.

The term "expression" as used herein refers to a process by which a gene produces a biochemical, for example, an RNA or polypeptide. The process includes any manifestation of the functional presence of the gene within the cell including, without limitation, gene knockdown as well as both transient expression and stable expression. It includes without limitation transcription of the gene into messenger RNA (mRNA), transfer RNA (tRNA), small hairpin RNA (shRNA), small interfering RNA (siRNA) or any other RNA product, and the translation of such mRNA into polypeptide(s). If the final desired product is a biochemical, expression includes the creation of that biochemical and any precursors. Expression of a gene produces a "gene product." As used herein, a gene product can be either a nucleic acid, *e.g.*, a messenger RNA produced by transcription of a gene, or a polypeptide which is translated from a transcript. Gene products described herein further include nucleic acids with post transcriptional modifications, *e.g.*, polyadenylation, or polypeptides with post translational modifications, *e.g.*, methylation, glycosylation, the addition of lipids, association with other protein subunits, proteolytic cleavage, and the like.

As used herein, the term "sample" refers to any biological material obtained from a subject or patient. In one aspect, a sample can comprise blood, cerebrospinal fluid ("CSF"), or urine. In other aspects, a sample can comprise whole blood, plasma, B cells enriched from blood samples, and cultured cells (*e.g.*, B cells from a subject). A sample can also include a biopsy or tissue sample including neural tissue. In still other aspects, a sample can comprise whole cells and/or a lysate of the cells. Blood samples can be collected by methods known in the art. In one aspect, the pellet can be resuspended by vortexing at 4°C in 200 µl buffer (20 mM Tris, pH. 7.5, 0.5% Nonidet, 1 mM EDTA, 1 mM PMSF, 0.1M NaCl, IX Sigma Protease Inhibitor, and IX Sigma Phosphatase Inhibitors 1 and 2). The suspension can be kept on ice for 20 minutes with intermittent vortexing. After spinning at 15,000 x g for 5 minutes at about 4°C, aliquots of supernatant can be stored at about -70°C.

As used herein, the terms "treat" or "treatment" refer to both therapeutic treatment and prophylactic or preventative measures, wherein the object is to prevent or slow down (lessen) an undesired physiological change or disorder, such as the development of Parkinsonism. Beneficial or desired clinical results include, but are not limited to, alleviation of symptoms, diminishment of extent of disease, stabilized (*i.e.*, not worsening) state of disease, delay or slowing of disease progression, amelioration or palliation of the disease state, and remission

(whether partial or total), whether detectable or undetectable. "Treatment" can also mean prolonging survival as compared to expected survival if not receiving treatment. Those in need of treatment include those already with the condition or disorder as well as those prone to have the condition or disorder or those in which the manifestation of the condition or disorder is to be prevented.

By "subject" or "individual" or "animal" or "patient" or „mammal," is meant any subject, particularly a mammalian subject, *e.g.*, a human patient, for whom diagnosis, prognosis, prevention, or therapy is desired.

II. Antibodies

The present invention generally relates to human anti-α-synuclein antibodies and antigen-binding fragments thereof, which preferably demonstrate the immunological binding characteristics and/or biological properties as outlined for the antibodies illustrated in the Examples. In accordance with the present invention human monoclonal antibodies specific for α-synuclein were cloned from a pool of aged subjects.

In the course of the experiments performed in accordance with the present invention initial attempts failed to clone α-synuclein specific antibodies but almost always resulted in false-positive clones. Further investigation of these clones revealed that they produced antibodies recognizing proteins of *E. coli*. In order to circumvent this problem, antibodies in conditioned media of human memory B cell cultures were screened in parallel for binding to coated full-length alpha synuclein monomer and absence of binding to *E. coli*. proteins and bovine serum albumin (BSA). In particular, B cell conditioned medium was preabsorbed with *E. coli* proteins prior to subjecting the medium to an ELISA assay for screening of α-synuclein binding human antibodies.

Initial attempts to isolating specific antibodies were focused at pools of human subjects with high plasma binding activity to α-synuclein, suggestive of elevated levels of circulating α-synuclein antibodies plasma. Unexpectedly, these attempts failed to produce α-synuclein specific human memory B cells and the antibodies described in the current invention were isolated from pools of subjects with low plasma reactivity to α-synuclein.

Due to this measure, several antibodies could be isolated. Selected antibodies were further analyzed for class and light chain subclass determination. Selected relevant antibody messages from memory B cell cultures are then transcribed by RT-PCR, cloned and combined into expression vectors for recombinant production; see the appended Examples. Recombinant expression of the human antibodies in HEK293 or CHO cells and the subsequent characterization of their binding specificities towards full-length α-synuclein and truncated forms thereof (Fig. 2), on Western Blot (Fig. 4) as well as to β- and γ-synuclein (Fig. 3) confirmed that for the first time human antibodies have been cloned that are highly specific for α-synuclein and recognize different epitopes within the α-synuclein protein.

Thus, the present invention generally relates to an isolated naturally occurring human monoclonal anti-α-synuclein antibody and binding fragments, derivatives and variants thereof. As demonstrated in the Examples and shown in Fig. 3 the human monoclonal anti-α-synuclein antibody of the present invention is preferably characterized in specifically binding α-synuclein compared to β-synuclein and γ-synuclein. Advantageously, the antibody is capable of specifically binding α-synuclein in the native monomer form and/or in the oligomeric or aggregated form. In addition, the human anti-α-synuclein antibody of the present invention may be further characterized by its ability to recognize α-synuclein on Western Blotting; see Fig. 4.

In one embodiment, the present invention is directed to an anti-α-synuclein antibody, or antigen-binding fragment, variant or derivatives thereof, where the antibody specifically binds to the same epitope of α-synuclein as a reference antibody selected from the group consisting of NI-202.3G12, NI-202.12F4 or NI-202.3D8. As illustrated in the Examples, antibody NI-202.3G12 binds wild type (wt) α-synuclein but not to α-synuclein truncations in a direct ELISA assay, pointing to a structural epitope of NI-202.3G12; see Fig. 2A. In contrast, antibody NI-202.12F4 binds to α-synuclein truncations containing the N-terminal amphipathic repeat region (amino acids 1-60) in a direct ELISA assay, pointing to an N-terminal epitope of NI-202.12F4; see Fig. 2B. In addition, preliminary results of direct ELISA assays performed with antibody NI-202.3D8 revealed that NI-202.3D8 specifically recognizes the C-terminus of α-synuclein, preferably amino acids 96-140.

Furthermore, without intending to be bound by initial experimental observations further preliminary experiments give rise to assume that antibody NI-202.3D8 preferentially binds to

α-synuclein monomer rather than fibrils in a direct ELISA antibody assay while antibodies NI-202.12F4 and NI-202.3G12 preferentially bind α-synuclein aggregates or fibrils over the monomeric form of α-synuclein. Hence, the present invention provides a set of human anti-α-synuclein antibodies with different specificities, which are thus particularly useful for diagnostic and therapeutic purposes.

In one embodiment, the antibody of the present invention exhibits the binding properties of the exemplary NI-202.12F4 antibody as described in any one of Examples 1 to 5. For example, in one embodiment the anti-α-synuclein antibody of the present invention preferentially recognizes human rather than mouse α-synuclein, in particular when analyzed according to Example 3. In addition, or alternatively, the anti-α-synuclein antibody of the present invention preferentially recognizes aggregated or misfolded forms α-synuclein rather than physiological monomeric forms, in particular when analyzed according to Example 3. In addition, or alternatively, the anti-α-synuclein antibody of the present invention binds to disease causing mutants of human α-synuclein, in particular those described in Example 3. In this context, the binding specificities may be in the range as shown for the exemplary NI-202.12F4 antibody in Fig. 5, i.e. having half maximal effective concentrations (EC50) of about 100 to 1000 pM, preferably an EC50 of about 100 to 500 pM for wild-type α-synuclein or a disease causing mutant thereof.

Hence, the anti-α-synuclein antibody of the present invention preferably preferentially binds to pathological forms of α-synuclein in brain, e.g. pathological aggregates of α-synuclein as exemplified by Western blot and immunohistochemical staining described in Example 3. Accordingly, in another additional or alternative embodiment the anti-α-synuclein antibody of the present invention preferentially binds to a conformational epitope of human α-synuclein and does not significantly bind N-terminal derived fragments of α-synuclein consisting of amino acids 1-20; 21-40; 41-60; 11-30; or 31-50.

The present invention is also drawn to an antibody, or antigen-binding fragment, variant or derivatives thereof, where the antibody comprises an antigen-binding domain identical to that of an antibody selected from the group consisting of NI-202.3G12, NI-202.12F4 or NI-202.3D8.

The present invention further exemplifies several such binding molecules, *e.g.* antibodies and binding fragments thereof, which may be characterized by comprising in their variable region, *e.g.* binding domain at least one complementarity determining region (CDR) of the V_H and/or V_L variable region comprising any one of the amino acid sequences depicted in Fig. 1. The corresponding nucleotide sequences encoding the above-identified variable regions are set forth in the attached sequence listing. An exemplary set of CDRs of the above amino acid sequences of the V_H and/or V_L region as depicted in Fig. 1 is also indicated in the appended sequence listing. However, as discussed in the following the person skilled in the art is well aware of the fact that in addition or alternatively CDRs may be used, which differ in their amino acid sequence from those set forth in Fig. 1 by one, two, three or even more amino acids in case of CDR2 and CDR3.

In one embodiment, the antibody of the present invention is any one of the antibodies comprising an amino acid sequence of the V_H and/or V_L region as depicted in Fig. 1. Alternatively, the antibody of the present invention is an antibody or antigen-binding fragment, derivative or variant thereof, which competes for binding to α-synuclein with at least one of the antibodies having the V_H and/or V_L region as depicted in Fig. 1. Those antibodies may be human as well, in particular for therapeutic applications. Alternatively, the antibody is a murine, murinized and chimeric murine-human antibody, which are particularly useful for diagnostic methods and studies in animals.

As mentioned above, due to its generation upon a human immune response the human monoclonal antibody of the present invention will recognize epitopes which are of particular physiological relevance and which might not be accessible or less immunogenic in case of immunization processes for the generation of for example mouse monoclonal antibodies and in *in vitro* screening of phage display libraries, respectively. Accordingly, it is prudent to stipulate that the epitope of the human anti-α-synuclein antibody of the present invention is unique and no other antibody which is capable of binding to the epitope recognized by the human monoclonal antibody of the present invention exists. Therefore, the present invention also extends generally to anti-α-synuclein antibodies and α-synuclein binding molecules which compete with the human monoclonal antibody of the present invention for specific binding to α-synuclein. The present invention is more specifically directed to an antibody, or antigen-binding fragment, variant or derivatives thereof, where the antibody specifically binds

to the same epitope of α-synuclein as a reference antibody selected from the group consisting of NI-202.3G12, NI-202.12F4 or NI-202.3D8.

Competition between antibodies is determined by an assay in which the immunoglobulin under test inhibits specific binding of a reference antibody to a common antigen, such as α-synuclein. Numerous types of competitive binding assays are known, for example: solid phase direct or indirect radioimmunoassay (RIA), solid phase direct or indirect enzyme immunoassay (EIA), sandwich competition assay; see Stahli *et al.*, Methods in Enzymology 9 (1983), 242-253; solid phase direct biotin-avidin EIA; see Kirkland *et al.*, J. Immunol. 137 (1986), 3614-3619 and Cheung *et al.*, Virology 176 (1990), 546-552; solid phase direct labeled assay, solid phase direct labeled sandwich assay; see Harlow and Lane, Antibodies, A Laboratory Manual, Cold Spring Harbor Press (1988); solid phase direct label RIA using I^{125} label; see Morel *et al*, Molec. Immunol. 25 (1988), 7-15 and Moldenhauer *et al.*, Scand. J. Immunol. 32 (1990), 77-82. Typically, such an assay involves the use of purified α-synuclein or aggregates thereof bound to a solid surface or cells bearing either of these, an unlabelled test immunoglobulin and a labeled reference immunoglobulin, *i.e.* the human monoclonal antibody of the present invention. Competitive inhibition is measured by determining the amount of label bound to the solid surface or cells in the presence of the test immunoglobulin. Usually the test immunoglobulin is present in excess. Preferably, the competitive binding assay is performed under conditions as described for the ELISA assay in the appended Examples. Antibodies identified by competition assay (competing antibodies) include antibodies binding to the same epitope as the reference antibody and antibodies binding to an adjacent epitope sufficiently proximal to the epitope bound by the reference antibody for steric hindrance to occur. Usually, when a competing antibody is present in excess, it will inhibit specific binding of a reference antibody to a common antigen by at least 50% or 75%. Hence, the present invention is further drawn to an antibody, or antigen-binding fragment, variant or derivatives thereof, where the antibody competitively inhibits a reference antibody selected from the group consisting of NI-202.3G12, NI-202.12F4 or NI-202.3D8 from binding to α-synuclein.

In another embodiment, the present invention provides an isolated polypeptide comprising, consisting essentially of, or consisting of an immunoglobulin heavy chain variable region (V_H), where at least one of V_H-CDRs of the heavy chain variable region or at least two of the

V_H-CDRs of the heavy chain variable region are at least 80%, 85%, 90% or 95% identical to reference heavy chain V_H-CDR1, V_H-CDR2 or V_H-CDR3 amino acid sequences from the antibodies disclosed herein. Alternatively, the V_H-CDR1, V_H-CDR2 and V_H-CDR3 regions of the V_H are at least 80%, 85%, 90% or 95% identical to reference heavy chain V_H -CDR1, V_H-CDR2 and V_H-CDR3 amino acid sequences from the antibodies disclosed herein. Thus, according to this embodiment a heavy chain variable region of the invention has V_H-CDR1, V_H-CDR2 and V_H-CDR3 polypeptide sequences related to the groups shown in Fig. 1. While Fig. 1 shows V_H-CDRs defined by the Kabat system, other CDR definitions, *e.g.*, V_H-CDRs defined by the Chothia system, are also included in the present invention, and can be easily identified by a person of ordinary skill in the art using the data presented in Fig. 1.

In another embodiment, the present invention provides an isolated polypeptide comprising, consisting essentially of, or consisting of an immunoglobulin heavy chain variable region (V_H) in which the V_H-CDR1, V_H-CDR2 and V_H-CDR3 regions have polypeptide sequences which are identical to the V_H-CDR1, V_H-CDR2 and V_H-CDR3 groups shown in Fig. 1.

In another embodiment, the present invention provides an isolated polypeptide comprising, consisting essentially of, or consisting of an immunoglobulin heavy chain variable region (V_H) in which the V_H-CDR1, V_H-CDR2 and V_H-CDR3 regions have polypeptide sequences which are identical to the V_H-CDR1, V_H-CDR2 and V_H-CDR3 groups shown in Fig. 1, except for one, two, three, four, five, or six amino acid substitutions in any one V_H-CDR. In certain embodiments the amino acid substitutions are conservative.

In another embodiment, the present invention provides an isolated polypeptide comprising, consisting essentially of, or consisting of an immunoglobulin light chain variable region (V_L), where at least one of the V_L-CDRs of the light chain variable region or at least two of the V_L-CDRs of the light chain variable region are at least 80%, 85%, 90% or 95% identical to reference light chain V_L-CDR1, V_L-CDR2 or V_L-CDR3 amino acid sequences from antibodies disclosed herein. Alternatively, the V_L-CDR1, V_L-CDR2 and V_L-CDR3 regions of the V_L are at least 80%, 85%, 90% or 95% identical to reference light chain V_L-CDR1, V_L-CDR2 and V_L-CDR3 amino acid sequences from antibodies disclosed herein. Thus, according to this embodiment a light chain variable region of the invention has V_L-CDR1, V_L-CDR2 and V_L-CDR3 polypeptide sequences related to the polypeptides shown in Fig. 1. While Fig.

1 shows V_L-CDRs defined by the Kabat system, other CDR definitions, *e.g.*, V_L-CDRs defined by the Chothia system, are also included in the present invention.

In another embodiment, the present invention provides an isolated polypeptide comprising, consisting essentially of, or consisting of an immunoglobulin light chain variable region (V_L) in which the V_L-CDR1, V_L-CDR2 and V_L-CDR3 regions have polypeptide sequences which are identical to the V_L-CDR1, V_L-CDR2 and V_L-CDR3 groups shown in Fig. 1.

In another embodiment, the present invention provides an isolated polypeptide comprising, consisting essentially of, or consisting of an immunoglobulin heavy chain variable region (V_L) in which the V_L-CDR1, V_L-CDR2 and V_L-CDR3 regions have polypeptide sequences which are identical to the V_L-CDR1, V_L-CDR2 and V_L-CDR3 groups shown in Fig. 1, except for one, two, three, four, five, or six amino acid substitutions in any one V_L-CDR. In certain embodiments the amino acid substitutions are conservative.

An immunoglobulin or its encoding cDNA may be further modified. Thus, in a further embodiment the method of the present invention comprises any one of the step(s) of producing a chimeric antibody, murinized antibody, single-chain antibody, Fab-fragment, bi-specific antibody, fusion antibody, labeled antibody or an analog of any one of those. Corresponding methods are known to the person skilled in the art and are described, *e.g.*, in Harlow and Lane "Antibodies, A Laboratory Manual", CSH Press, Cold Spring Harbor (1988). When derivatives of said antibodies are obtained by the phage display technique, surface plasmon resonance as employed in the BIAcore system can be used to increase the efficiency of phage antibodies which bind to the same epitope as that of any one of the antibodies described herein (Schier, Human Antibodies Hybridomas 7 (1996), 97-105; Malmborg, J. Immunol. Methods 183 (1995), 7-13). The production of chimeric antibodies is described, for example, in international application WO89/09622. Methods for the production of humanized antibodies are described in, *e.g.*, European application EP-A1 0 239 400 and international application WO90/07861. A further source of antibodies to be utilized in accordance with the present invention are so-called xenogeneic antibodies. The general principle for the production of xenogeneic antibodies such as human-like antibodies in mice is described in, *e.g.*, international applications WO91/10741, WO94/02602, WO96/34096 and WO 96/33735. As discussed above, the antibody of the invention may exist in a variety of

forms besides complete antibodies; including, for example, Fv, Fab and F(ab)2, as well as in single chains; see *e.g.* international application WO88/09344.

The antibodies of the present invention or their corresponding immunoglobulin chain(s) can be further modified using conventional techniques known in the art, for example, by using amino acid deletion(s), insertion(s), substitution(s), addition(s), and/or recombination(s) and/or any other modification(s) known in the art either alone or in combination. Methods for introducing such modifications in the DNA sequence underlying the amino acid sequence of an immunoglobulin chain are well known to the person skilled in the art; see, *e.g.*, Sambrook, *Molecular Cloning A Laboratory Manual*, Cold Spring Harbor Laboratory (1989) N.Y. and Ausubel, *Current Protocols in Molecular Biology*, Green Publishing Associates and Wiley Interscience, N.Y. (1994). Modifications of the antibody of the invention include chemical and/or enzymatic derivatizations at one or more constituent amino acids, including side chain modifications, backbone modifications, and N- and C-terminal modifications including acetylation, hydroxylation, methylation, amidation, and the attachment of carbohydrate or lipid moieties, cofactors, and the like. Likewise, the present invention encompasses the production of chimeric proteins which comprise the described antibody or some fragment thereof at the amino terminus fused to heterologous molecule such as an immunostimulatory ligand at the carboxyl terminus; see, *e.g.*, international application WO00/30680 for corresponding technical details.

Additionally, the present invention encompasses peptides including those containing a binding molecule as described above, for example containing the CDR3 region of the variable region of any one of the mentioned antibodies, in particular CDR3 of the heavy chain since it has frequently been observed that heavy chain CDR3 (HCDR3) is the region having a greater degree of variability and a predominant participation in antigen-antibody interaction. Such peptides may easily be synthesized or produced by recombinant means to produce a binding agent useful according to the invention. Such methods are well known to those of ordinary skill in the art. Peptides can be synthesized for example, using automated peptide synthesizers which are commercially available. The peptides can also be produced by recombinant techniques by incorporating the DNA expressing the peptide into an expression vector and transforming cells with the expression vector to produce the peptide.

Hence, the present invention relates to any binding molecule, *e.g.*, an antibody or binding fragment thereof which is oriented towards the human anti-α-synuclein antibodies of the present invention and display the mentioned properties, *i.e.* which specifically recognize α-synuclein. Such antibodies and binding molecules can be tested for their binding specificity and affinity by ELISA and Western Blot and immunohistochemisty as described herein, *see, e.g.*, the Examples. Furthermore, preliminary results of subsequent experiments performed in accordance with the present invention revealed that the human ant-α-synuclein antibody of the present invention, in particular antibody NI-202.12F4 recognizes α-synuclein inclusion bodies present on human brain sections of patients who suffered from dementia with Lewy bodies (DLB) or Parkinson's disease (PD). Thus, in a particular preferred embodiment of the present invention, the human antibody or binding fragment, derivative or variant thereof recognizes α-synuclein on human DLB or PD brain sections.

As an alternative to obtaining immunoglobulins directly from the culture of immortalized B cells or B memory cells, the immortalized cells can be used as a source of rearranged heavy chain and light chain loci for subsequent expression and/or genetic manipulation. Rearranged antibody genes can be reverse transcribed from appropriate mRNAs to produce cDNA. If desired, the heavy chain constant region can be exchanged for that of a different isotype or eliminated altogether. The variable regions can be linked to encode single chain Fv regions. Multiple Fv regions can be linked to confer binding ability to more than one target or chimeric heavy and light chain combinations can be employed. Once the genetic material is available, design of analogs as described above which retain both their ability to bind the desired target is straightforward. Methods for the cloning of antibody variable regions and generation of recombinant antibodies are known to the person skilled in the art and are described, for example, Gilliland *et al.*, Tissue Antigens 47 (1996), 1-20; Doenecke *et al.*, Leukemia 11 (1997), 1787-1792.

Once the appropriate genetic material is obtained and, if desired, modified to encode an analog, the coding sequences, including those that encode, at a minimum, the variable regions of the heavy and light chain, can be inserted into expression systems contained on vectors which can be transfected into standard recombinant host cells. A variety of such host cells may be used; for efficient processing, however, mammalian cells are preferred. Typical

mammalian cell lines useful for this purpose include, but are not limited to, CHO cells, HEK 293 cells, or NSO cells.

The production of the antibody or analog is then undertaken by culturing the modified recombinant host under culture conditions appropriate for the growth of the host cells and the expression of the coding sequences. The antibodies are then recovered by isolating them from the culture. The expression systems are preferably designed to include signal peptides so that the resulting antibodies are secreted into the medium; however, intracellular production is also possible.

In accordance with the above, the present invention also relates to a polynucleotide encoding the antibody or equivalent binding molecule of the present invention, in case of the antibody preferably at least a variable region of an immunoglobulin chain of the antibody described above. Typically, said variable region encoded by the polynucleotide comprises at least one complementarity determining region (CDR) of the V_H and/or V_L of the variable region of the said antibody.

The person skilled in the art will readily appreciate that the variable domain of the antibody having the above-described variable domain can be used for the construction of other polypeptides or antibodies of desired specificity and biological function. Thus, the present invention also encompasses polypeptides and antibodies comprising at least one CDR of the above-described variable domain and which advantageously have substantially the same or similar binding properties as the antibody described in the appended examples. The person skilled in the art knows that binding affinity may be enhanced by making amino acid substitutions within the CDRs or within the hypervariable loops (Chothia and Lesk, J. Mol. Biol. 196 (1987), 901-917) which partially overlap with the CDRs as defined by Kabat; *see, e.g.*, Riechmann, *et al*, Nature 332 (1988), 323-327. Thus, the present invention also relates to antibodies wherein one or more of the mentioned CDRs comprise one or more, preferably not more than two amino acid substitutions. Preferably, the antibody of the invention comprises in one or both of its immunoglobulin chains two or all three CDRs of the variable regions as set forth in Fig. 1.

Binding molecules, *e.g.*, antibodies, or antigen-binding fragments, variants, or derivatives thereof of the invention, as known by those of ordinary skill in the art, can comprise a constant region which mediates one or more effector functions. For example, binding of the C1 component of complement to an antibody constant region may activate the complement system. Activation of complement is important in the opsonization and lysis of cell pathogens. The activation of complement also stimulates the inflammatory response and may also be involved in autoimmune hypersensitivity. Further, antibodies bind to receptors on various cells via the Fc region, with a Fc receptor binding site on the antibody Fc region binding to a Fc receptor (FcR) on a cell. There are a number of Fc receptors which are specific for different classes of antibody, including IgG (gamma receptors), IgE (epsilon receptors), IgA (alpha receptors) and IgM (mu receptors). Binding of antibody to Fc receptors on cell surfaces triggers a number of important and diverse biological responses including engulfment and destruction of antibody-coated particles, clearance of immune complexes, lysis of antibody-coated target cells by killer cells (called antibody-dependent cell-mediated cytotoxicity, or ADCC), release of inflammatory mediators, placental transfer and control of immunoglobulin production.

Accordingly, certain embodiments of the present invention include an antibody, or antigen-binding fragment, variant, or derivative thereof, in which at least a fraction of one or more of the constant region domains has been deleted or otherwise altered so as to provide desired biochemical characteristics such as reduced effector functions, the ability to non-covalently dimerize, increased ability to localize at the site of α-synuclein aggregation and deposition, reduced serum half-life, or increased serum half-life when compared with a whole, unaltered antibody of approximately the same immunogenicity. For example, certain antibodies for use in the diagnostic and treatment methods described herein are domain deleted antibodies which comprise a polypeptide chain similar to an immunoglobulin heavy chain, but which lack at least a portion of one or more heavy chain domains. For instance, in certain antibodies, one entire domain of the constant region of the modified antibody will be deleted, for example, all or part of the CH2 domain will be deleted. In other embodiments, certain antibodies for use in the diagnostic and treatment methods described herein have a constant region, *e.g.*, an IgG heavy chain constant region, which is altered to eliminate glycosylation, referred to elsewhere herein as aglycosylated or "agly" antibodies. Such "agly" antibodies may be prepared enzymatically as well as by engineering the consensus glycosylation site(s) in the constant

region. While not being bound by theory, it is believed that "agly" antibodies may have an improved safety and stability profile *in vivo*. Methods of producing aglycosylated antibodies, having desired effector function are found for example in international application WO2005/018572, which is incorporated by reference in its entirety.

In certain antibodies, or antigen-binding fragments, variants, or derivatives thereof described herein, the Fc portion may be mutated to decrease effector function using techniques known in the art. For example, the deletion or inactivation (through point mutations or other means) of a constant region domain may reduce Fc receptor binding of the circulating modified antibody thereby increasing α-synuclein localization. In other cases it may be that constant region modifications consistent with the instant invention moderate complement binding and thus reduce the serum half life and nonspecific association of a conjugated cytotoxin. Yet other modifications of the constant region may be used to modify disulfide linkages or oligosaccharide moieties that allow for enhanced localization due to increased antigen specificity or antibody flexibility. The resulting physiological profile, bioavailability and other biochemical effects of the modifications, such as α-synuclein localization, biodistribution and serum half-life, may easily be measured and quantified using well know immunological techniques without undue experimentation.

In certain antibodies, or antigen-binding fragments, variants, or derivatives thereof described herein, the Fc portion may be mutated or exchanged for alternative protein sequences to increase the cellular uptake of antibodies by way of example by enhancing receptor-mediated endocytosis of antibodies via Fcγ receptors, LRP, or Thy1 receptors or by 'SuperAntibody Technology', which is said to enable antibodies to be shuttled into living cells without harming them (Expert Opin. Biol. Ther. (2005), 237-241). For example, the generation of fusion proteins of the antibody binding region and the cognate protein ligands of cell surface receptors or bi- or multi-specific antibodies with a specific sequences biding to α-synuclein as well as a cell surface receptor may be engineered using techniques known in the art.

In certain antibodies, or antigen-binding fragments, variants, or derivatives thereof described herein, the Fc portion may be mutated or exchanged for alternative protein sequences or the antibody may be chemically modified to increase its blood brain barrier penetration.

Modified forms of antibodies, or antigen-binding fragments, variants, or derivatives thereof of the invention can be made from whole precursor or parent antibodies using techniques known in the art. Exemplary techniques are discussed in more detail herein. Antibodies, or antigen-binding fragments, variants, or derivatives thereof of the invention can be made or manufactured using techniques that are known in the art. In certain embodiments, antibody molecules or fragments thereof are "recombinantly produced," *i.e.*, are produced using recombinant DNA technology. Exemplary techniques for making antibody molecules or fragments thereof are discussed in more detail elsewhere herein.

Antibodies, or antigen-binding fragments, variants, or derivatives thereof of the invention also include derivatives that are modified, *e.g.*, by the covalent attachment of any type of molecule to the antibody such that covalent attachment does not prevent the antibody from specifically binding to its cognate epitope. For example, but not by way of limitation, the antibody derivatives include antibodies that have been modified, *e.g.*, by glycosylation, acetylation, pegylation, phosphorylation, amidation, derivatization by known protecting/blocking groups, proteolytic cleavage, linkage to a cellular ligand or other protein, etc. Any of numerous chemical modifications may be carried out by known techniques, including, but not limited to specific chemical cleavage, acetylation, formylation, metabolic synthesis of tunicamycin, etc. Additionally, the derivative may contain one or more non-classical amino acids.

In particular preferred embodiments, antibodies, or antigen-binding fragments, variants, or derivatives thereof of the invention will not elicit a deleterious immune response in the animal to be treated, *e.g.*, in a human. In certain embodiments, binding molecules, *e.g.*, antibodies, or antigen-binding fragments thereof of the invention are derived from a patient, *e.g.*, a human patient, and are subsequently used in the same species from which they are derived, *e.g.*, human, alleviating or minimizing the occurrence of deleterious immune responses.

De-immunization can also be used to decrease the immunogenicity of an antibody. As used herein, the term "de-immunization" includes alteration of an antibody to modify T cell epitopes; *see, e.g.*, international applications WO98/52976 and WO00/34317. For example, V_H and V_L sequences from the starting antibody are analyzed and a human T cell epitope "map" from each V region showing the location of epitopes in relation to complementarity determining regions (CDRs) and other key residues within the sequence. Individual T cell

epitopes from the T cell epitope map are analyzed in order to identify alternative amino acid substitutions with a low risk of altering activity of the final antibody. A range of alternative V_H and V_L sequences are designed comprising combinations of amino acid substitutions and these sequences are subsequently incorporated into a range of binding polypeptides, *e.g.*, α-synuclein-specific antibodies or immunospecific fragments thereof for use in the diagnostic and treatment methods disclosed herein, which are then tested for function. Typically, between 12 and 24 variant antibodies are generated and tested. Complete heavy and light chain genes comprising modified V and human C regions are then cloned into expression vectors and the subsequent plasmids introduced into cell lines for the production of whole antibody. The antibodies are then compared in appropriate biochemical and biological assays, and the optimal variant is identified.

Monoclonal antibodies can be prepared using a wide variety of techniques known in the art including the use of hybridoma, recombinant, and phage display technologies, or a combination thereof. For example, monoclonal antibodies can be produced using hybridoma techniques including those known in the art and taught, for example, in Harlow *et al.*, Antibodies: A Laboratory Manual, Cold Spring Harbor Laboratory Press, 2nd ed. (1988); Hammerling *et al.*, in: *Monoclonal Antibodies and T-Cell Hybridomas* Elsevier, N.Y., 563-681 (1981), said references incorporated by reference in their entireties. The term "monoclonal antibody" as used herein is not limited to antibodies produced through hybridoma technology. The term "monoclonal antibody" refers to an antibody that is derived from a single clone, including any eukaryotic, prokaryotic, or phage clone, and not the method by which it is produced. Thus, the term "monoclonal antibody" is not limited to antibodies produced through hybridoma technology. In certain embodiments, antibodies of the present invention are derived from human B cells which have been immortalized via transformation with Epstein-Barr virus, as described herein.

In the well known hybridoma process (Kohler *et al.*, Nature 256 (1975), 495) the relatively short-lived, or mortal, lymphocytes from a mammal, *e.g.*, B cells derived from a human subject as described herein, are fused with an immortal tumor cell line (*e.g.*,. a myeloma cell line), thus, producing hybrid cells or "hybridomas" which are both immortal and capable of producing the genetically coded antibody of the B cell. The resulting hybrids are segregated into single genetic strains by selection, dilution, and re-growth with each individual strain

comprising specific genes for the formation of a single antibody. They produce antibodies, which are homogeneous against a desired antigen and, in reference to their pure genetic parentage, are termed "monoclonal".

Hybridoma cells thus prepared are seeded and grown in a suitable culture medium that preferably contains one or more substances that inhibit the growth or survival of the unfused, parental myeloma cells. Those skilled in the art will appreciate that reagents, cell lines and media for the formation, selection and growth of hybridomas are commercially available from a number of sources and standardized protocols are well established. Generally, culture medium in which the hybridoma cells are growing is assayed for production of monoclonal antibodies against the desired antigen. The binding specificity of the monoclonal antibodies produced by hybridoma cells is determined by *in vitro* assays such as immunoprecipitation, radioimmunoassay (RIA) or enzyme-linked immunoabsorbent assay (ELISA) as described herein. After hybridoma cells are identified that produce antibodies of the desired specificity, affinity and/or activity, the clones may be subcloned by limiting dilution procedures and grown by standard methods; *see, e.g.,* Goding, *Monoclonal Antibodies: Principles and Practice*, Academic Press, pp 59-103 (1986). It will further be appreciated that the monoclonal antibodies secreted by the subclones may be separated from culture medium, ascites fluid or serum by conventional purification procedures such as, for example, protein-A, hydroxylapatite chromatography, gel electrophoresis, dialysis or affinity chromatography.

In another embodiment, lymphocytes can be selected by micromanipulation and the variable genes isolated. For example, peripheral blood mononuclear cells can be isolated from an immunized or naturally immune mammal, *e.g.*, a human, and cultured for about 7 days *in vitro*. The cultures can be screened for specific IgGs that meet the screening criteria. Cells from positive wells can be isolated. Individual Ig-producing B cells can be isolated by FACS or by identifying them in a complement-mediated hemolytic plaque assay. Ig-producing B cells can be micromanipulated into a tube and the V_H and V_L genes can be amplified using, *e.g.*, RT-PCR. The V_H and V_L genes can be cloned into an antibody expression vector and transfected into cells (*e.g.*, eukaryotic or prokaryotic cells) for expression.

Alternatively, antibody-producing cell lines may be selected and cultured using techniques well known to the skilled artisan. Such techniques are described in a variety of laboratory

manuals and primary publications. In this respect, techniques suitable for use in the invention as described below are described in *Current Protocols in Immunology*, Coligan *et al.*, Eds., Green Publishing Associates and Wiley-Interscience, John Wiley and Sons, New York (1991) which is herein incorporated by reference in its entirety, including supplements.

Antibody fragments that recognize specific epitopes may be generated by known techniques. For example, Fab and $F(ab')_2$ fragments may be produced recombinantly or by proteolytic cleavage of immunoglobulin molecules, using enzymes such as papain (to produce Fab fragments) or pepsin (to produce $F(ab')_2$ fragments). $F(ab')_2$ fragments contain the variable region, the light chain constant region and the CH1 domain of the heavy chain. Such fragments are sufficient for use, for example, in immunodiagnostic procedures involving coupling the immunospecific portions of immunoglobulins to detecting reagents such as radioisotopes.

Completely human antibodies, such as described herein, are particularly desirable for therapeutic treatment of human patients. Human antibodies of the present invention are isolated, *e.g.*, from elderly subjects who because of their age may be suspected to be at risk of developing a disorder, *e.g.*, Parkinson's disease, or a patient with the disorder but with an unusually stable disease course. However, though it is prudent to expect that elderly healthy and symptom-free subjects, respectively, more regularly will have developed protective anti-α-synuclein antibodies than younger subjects, the latter may be used as well as source for obtaining a human antibody of the present invention. This is particularly true for younger patients who are predisposed to develop a familial form of a synucleinopathic disease but remain symptom-free since their immune system and response functions more efficiently than that in older adults.

In one embodiment, an antibody of the invention comprises at least one heavy or light chain CDR of an antibody molecule. In another embodiment, an antibody of the invention comprises at least two CDRs from one or more antibody molecules. In another embodiment, an antibody of the invention comprises at least three CDRs from one or more antibody molecules. In another embodiment, an antibody of the invention comprises at least four CDRs from one or more antibody molecules. In another embodiment, an antibody of the invention comprises at least five CDRs from one or more antibody molecules. In another embodiment,

an antibody of the invention comprises at least six CDRs from one or more antibody molecules. Exemplary antibody molecules comprising at least one CDR that can be included in the subject antibodies are described herein.

Antibodies of the present invention can be produced by any method known in the art for the synthesis of antibodies, in particular, by chemical synthesis or preferably by recombinant expression techniques as described herein.

In one embodiment, an antibody, or antigen-binding fragment, variant, or derivative thereof of the invention comprises a synthetic constant region wherein one or more domains are partially or entirely deleted ("domain-deleted antibodies"). In certain embodiments compatible modified antibodies will comprise domain deleted constructs or variants wherein the entire CH2 domain has been removed (ΔCH2 constructs). For other embodiments a short connecting peptide may be substituted for the deleted domain to provide flexibility and freedom of movement for the variable region. Those skilled in the art will appreciate that such constructs are particularly preferred due to the regulatory properties of the CH2 domain on the catabolic rate of the antibody. Domain deleted constructs can be derived using a vector encoding an IgG_1 human constant domain, *see, e.g.*, international applications WO02/060955 and WO02/096948A2. This vector is engineered to delete the CH2 domain and provide a synthetic vector expressing a domain deleted IgG_1 constant region.

In certain embodiments, antibodies, or antigen-binding fragments, variants, or derivatives thereof of the present invention are minibodies. Minibodies can be made using methods described in the art, *see, e.g.*, US patent 5,837,821 or international application WO 94/09817.

In one embodiment, an antibody, or antigen-binding fragment, variant, or derivative thereof of the invention comprises an immunoglobulin heavy chain having deletion or substitution of a few or even a single amino acid as long as it permits association between the monomeric subunits. For example, the mutation of a single amino acid in selected areas of the CH2 domain may be enough to substantially reduce Fc binding and thereby increase α-synuclein localization. Similarly, it may be desirable to simply delete that part of one or more constant region domains that control the effector function (*e.g.* complement binding) to be modulated. Such partial deletions of the constant regions may improve selected characteristics of the

antibody (serum half-life) while leaving other desirable functions associated with the subject constant region domain intact. Moreover, as alluded to above, the constant regions of the disclosed antibodies may be synthetic through the mutation or substitution of one or more amino acids that enhances the profile of the resulting construct. In this respect it may be possible to disrupt the activity provided by a conserved binding site (*e.g.* Fc binding) while substantially maintaining the configuration and immunogenic profile of the modified antibody. Yet other embodiments comprise the addition of one or more amino acids to the constant region to enhance desirable characteristics such as effector function or provide for more cytotoxin or carbohydrate attachment. In such embodiments it may be desirable to insert or replicate specific sequences derived from selected constant region domains.

The present invention also provides antibodies that comprise, consist essentially of, or consist of, variants (including derivatives) of antibody molecules (*e.g.*, the V_H regions and/or V_L regions) described herein, which antibodies or fragments thereof immunospecifically bind to α-synuclein. Standard techniques known to those of skill in the art can be used to introduce mutations in the nucleotide sequence encoding an antibody, including, but not limited to, site-directed mutagenesis and PCR-mediated mutagenesis which result in amino acid substitutions. Preferably, the variants (including derivatives) encode less than 50 amino acid substitutions, less than 40 amino acid substitutions, less than 30 amino acid substitutions, less than 25 amino acid substitutions, less than 20 amino acid substitutions, less than 15 amino acid substitutions, less than 10 amino acid substitutions, less than 5 amino acid substitutions, less than 4 amino acid substitutions, less than 3 amino acid substitutions, or less than 2 amino acid substitutions relative to the reference V_H region, V_H-CDR1, V_H-CDR2, V_H-CDR3, V_L region, V_L-CDR1, V_L-CDR2, or V_L-CDR3. A "conservative amino acid substitution" is one in which the amino acid residue is replaced with an amino acid residue having a side chain with a similar charge. Families of amino acid residues having side chains with similar charges have been defined in the art. These families include amino acids with basic side chains (*e.g.*, lysine, arginine, histidine), acidic side chains (*e.g.*, aspartic acid, glutamic acid), uncharged polar side chains (*e.g.*, glycine, asparagine, glutamine, serine, threonine, tyrosine, cysteine), nonpolar side chains (*e.g.*, alanine, valine, leucine, isoleucine, proline, phenylalanine, methionine, tryptophan), beta-branched side chains (*e.g.*, threonine, valine, isoleucine) and aromatic side chains (*e.g.*, tyrosine, phenylalanine, tryptophan, histidine). Alternatively, mutations can be introduced randomly along all or part of the coding sequence, such as by saturation

mutagenesis, and the resultant mutants can be screened for biological activity to identify mutants that retain activity (*e.g.*, the ability to bind α-synuclein).

For example, it is possible to introduce mutations only in framework regions or only in CDR regions of an antibody molecule. Introduced mutations may be silent or neutral missense mutations, *e.g.*, have no, or little, effect on an antibody's ability to bind antigen, indeed some such mutations do not alter the amino acid sequence whatsoever. These types of mutations may be useful to optimize codon usage, or improve a hybridoma's antibody production. Codon-optimized coding regions encoding antibodies of the present invention are disclosed elsewhere herein. Alternatively, non-neutral missense mutations may alter an antibody's ability to bind antigen. The location of most silent and neutral missense mutations is likely to be in the framework regions, while the location of most non-neutral missense mutations is likely to be in CDR, though this is not an absolute requirement. One of skill in the art would be able to design and test mutant molecules with desired properties such as no alteration in antigen-binding activity or alteration in binding activity (*e.g.*, improvements in antigen-binding activity or change in antibody specificity). Following mutagenesis, the encoded protein may routinely be expressed and the functional and/or biological activity of the encoded protein, (*e.g.*, ability to immunospecifically bind at least one epitope of α-synuclein) can be determined using techniques described herein or by routinely modifying techniques known in the art.

III. Polynucleotides Encoding Antibodies

A polynucleotide encoding an antibody, or antigen-binding fragment, variant, or derivative thereof can be composed of any polyribonucleotide or polydeoxribonucleotide, which may be unmodified RNA or DNA or modified RNA or DNA. For example, a polynucleotide encoding an antibody, or antigen-binding fragment, variant, or derivative thereof can be composed of single- and double-stranded DNA, DNA that is a mixture of single- and double-stranded regions, single- and double-stranded RNA, and RNA that is mixture of single- and double-stranded regions, hybrid molecules comprising DNA and RNA that may be single-stranded or, more typically, double-stranded or a mixture of single- and double-stranded regions. In addition, a polynucleotide encoding an antibody, or antigen-binding fragment, variant, or derivative thereof can be composed of triple-stranded regions comprising RNA or DNA or both RNA and DNA. A polynucleotide encoding an antibody, or antigen-binding

fragment, variant, or derivative thereof may also contain one or more modified bases or DNA or RNA backbones modified for stability or for other reasons. "Modified" bases include, for example, tritylated bases and unusual bases such as inosine. A variety of modifications can be made to DNA and RNA; thus, "polynucleotide" embraces chemically, enzymatically, or metabolically modified forms.

An isolated polynucleotide encoding a non-natural variant of a polypeptide derived from an immunoglobulin (*e.g.*, an immunoglobulin heavy chain portion or light chain portion) can be created by introducing one or more nucleotide substitutions, additions or deletions into the nucleotide sequence of the immunoglobulin such that one or more amino acid substitutions, additions or deletions are introduced into the encoded protein. Mutations may be introduced by standard techniques, such as site-directed mutagenesis and PCR-mediated mutagenesis. Preferably, conservative amino acid substitutions are made at one or more non-essential amino acid residues.

As is well known, RNA may be isolated from the original B cells, hybridoma cells or from other transformed cells by standard techniques, such as guanidinium isothiocyanate extraction and precipitation followed by centrifugation or chromatography. Where desirable, mRNA may be isolated from total RNA by standard techniques such as chromatography on oligo dT cellulose. Suitable techniques are familiar in the art. In one embodiment, cDNAs that encode the light and the heavy chains of the antibody may be made, either simultaneously or separately, using reverse transcriptase and DNA polymerase in accordance with well known methods. PCR may be initiated by consensus constant region primers or by more specific primers based on the published heavy and light chain DNA and amino acid sequences. As discussed above, PCR also may be used to isolate DNA clones encoding the antibody light and heavy chains. In this case the libraries may be screened by consensus primers or larger homologous probes, such as human constant region probes.

DNA, typically plasmid DNA, may be isolated from the cells using techniques known in the art, restriction mapped and sequenced in accordance with standard, well known techniques set forth in detail, *e.g.*, in the foregoing references relating to recombinant DNA techniques. Of course, the DNA may be synthetic according to the present invention at any point during the isolation process or subsequent analysis.

In one embodiment, the present invention provides an isolated polynucleotide comprising, consisting essentially of, or consisting of a nucleic acid encoding an immunoglobulin heavy chain variable region (V_H), where at least one of the CDRs of the heavy chain variable region or at least two of the V_H-CDRs of the heavy chain variable region are at least 80%, 85%, 90% or 95% identical to reference heavy chain V_H-CDR1, V_H-CDR2, or V_H-CDR3 amino acid sequences from the antibodies disclosed herein. Alternatively, the V_H-CDR1, V_H-CDR2, or V_H-CDR3 regions of the V_H are at least 80%, 85%, 90% or 95% identical to reference heavy chain V_H-CDR1, V_H-CDR2, and V_H-CDR3 amino acid sequences from the antibodies disclosed herein. Thus, according to this embodiment a heavy chain variable region of the invention has V_H-CDR1, V_H-CDR2, or V_H-CDR3 polypeptide sequences related to the polypeptide sequences shown in Fig. 1.

In another embodiment, the present invention provides an isolated polynucleotide comprising, consisting essentially of, or consisting of a nucleic acid encoding an immunoglobulin light chain variable region (V_L), where at least one of the V_L-CDRs of the light chain variable region or at least two of the V_L-CDRs of the light chain variable region are at least 80%, 85%, 90% or 95% identical to reference light chain V_L-CDR1, V_L-CDR2, or V_L-CDR3 amino acid sequences from the antibodies disclosed herein. Alternatively, the V_L-CDR1, V_L-CDR2, or V_L-CDR3 regions of the V_L are at least 80%, 85%, 90% or 95% identical to reference light chain V_L-CDR1, V_L-CDR2, and V_L-CDR3 amino acid sequences from the antibodies disclosed herein. Thus, according to this embodiment a light chain variable region of the invention has V_L-CDR1, V_L-CDR2, or V_L-CDR3 polypeptide sequences related to the polypeptide sequences shown in Fig. 1.

In another embodiment, the present invention provides an isolated polynucleotide comprising, consisting essentially of, or consisting of a nucleic acid encoding an immunoglobulin heavy chain variable region (V_H) in which the V_H-CDR1, V_H-CDR2, and V_H-CDR3 regions have polypeptide sequences which are identical to the V_H-CDR1, V_H-CDR2, and V_H-CDR3 groups shown in Fig. 1 and in the appended sequence listing.

As known in the art, "sequence identity" between two polypeptides or two polynucleotides is determined by comparing the amino acid or nucleic acid sequence of one polypeptide or

polynucleotide to the sequence of a second polypeptide or polynucleotide. When discussed herein, whether any particular polypeptide is at least about 40%, 45%, 50%, 55%, 60%, 65%, 70%, 75%, 80%, 85%, 90% or 95% identical to another polypeptide can be determined using methods and computer programs/software known in the art such as, but not limited to, the BESTFIT program (Wisconsin Sequence Analysis Package, Version 8 for Unix, Genetics Computer Group, University Research Park, 575 Science Drive, Madison, WI 53711). BESTFIT uses the local homology algorithm of Smith and Waterman, Advances in Applied Mathematics 2 (1981), 482-489, to find the best segment of homology between two sequences. When using BESTFIT or any other sequence alignment program to determine whether a particular sequence is, for example, 95% identical to a reference sequence according to the present invention, the parameters are set, of course, such that the percentage of identity is calculated over the full length of the reference polypeptide sequence and that gaps in homology of up to 5% of the total number of amino acids in the reference sequence are allowed.

In a preferred embodiment of the present invention, the polynucleotide comprises, consists essentially of, or consists of a nucleic acid having a polynucleotide sequence of the V_H or V_L region of an anti-α-synuclein antibody as set forth in SEQ ID NOS: 2, 5, 8, 11, 14, 17 or 20. In this respect, the person skilled in the art will readily appreciate that the polynucleotides encoding at least the variable domain of the light and/or heavy chain may encode the variable domain of both immunoglobulin chains or only one.

The present invention also includes fragments of the polynucleotides of the invention, as described elsewhere. Additionally polynucleotides which encode fusion polynucleotides, Fab fragments, and other derivatives, as described herein, are also contemplated by the invention.

The polynucleotides may be produced or manufactured by any method known in the art. For example, if the nucleotide sequence of the antibody is known, a polynucleotide encoding the antibody may be assembled from chemically synthesized oligonucleotides, *e.g.*, as described in Kutmeier *et al.*, BioTechniques 17 (1994), 242, which, briefly, involves the synthesis of overlapping oligonucleotides containing portions of the sequence encoding the antibody, annealing and ligating of those oligonucleotides, and then amplification of the ligated oligonucleotides by PCR.

Alternatively, a polynucleotide encoding an antibody, or antigen-binding fragment, variant, or derivative thereof may be generated from nucleic acid from a suitable source. If a clone containing a nucleic acid encoding a particular antibody is not available, but the sequence of the antibody molecule is known, a nucleic acid encoding the antibody may be chemically synthesized or obtained from a suitable source (*e.g.*, an antibody cDNA library, or a cDNA library generated from, or nucleic acid, preferably polyA$^+$ RNA, isolated from, any tissue or cells expressing the α-synuclein-specific antibody, such as hybridoma cells selected to express an antibody) by PCR amplification using synthetic primers hybridizable to the 3' and 5' ends of the sequence or by cloning using an oligonucleotide probe specific for the particular gene sequence to identify, *e.g.*, a cDNA clone from a cDNA library that encodes the antibody. Amplified nucleic acids generated by PCR may then be cloned into replicable cloning vectors using any method well known in the art.

Once the nucleotide sequence and corresponding amino acid sequence of the antibody, or antigen-binding fragment, variant, or derivative thereof is determined, its nucleotide sequence may be manipulated using methods well known in the art for the manipulation of nucleotide sequences, *e.g.*, recombinant DNA techniques, site directed mutagenesis, PCR, etc. (see, for example, the techniques described in Sambrook *et al.*, *Molecular Cloning, A Laboratory Manual*, 2d Ed., Cold Spring Harbor Laboratory, Cold Spring Harbor, N.Y. (1990) and Ausubel *et al.*, eds., *Current Protocols in Molecular Biology*, John Wiley & Sons, NY (1998), which are both incorporated by reference herein in their entireties), to generate antibodies having a different amino acid sequence, for example to create amino acid substitutions, deletions, and/or insertions.

IV. Expression of Antibody Polypeptides

Following manipulation of the isolated genetic material to provide antibodies, or antigen-binding fragments, variants, or derivatives thereof of the invention, the polynucleotides encoding the antibodies are typically inserted in an expression vector for introduction into host cells that may be used to produce the desired quantity of antibody. Recombinant expression of an antibody, or fragment, derivative or analog thereof, *e.g.*, a heavy or light chain of an antibody which binds to a target molecule is described herein. Once a polynucleotide encoding an antibody molecule or a heavy or light chain of an antibody, or

portion thereof (preferably containing the heavy or light chain variable domain), of the invention has been obtained, the vector for the production of the antibody molecule may be produced by recombinant DNA technology using techniques well known in the art. Thus, methods for preparing a protein by expressing a polynucleotide containing an antibody encoding nucleotide sequence are described herein. Methods which are well known to those skilled in the art can be used to construct expression vectors containing antibody coding sequences and appropriate transcriptional and translational control signals. These methods include, for example, *in vitro* recombinant DNA techniques, synthetic techniques, and *in vivo* genetic recombination. The invention, thus, provides replicable vectors comprising a nucleotide sequence encoding an antibody molecule of the invention, or a heavy or light chain thereof, or a heavy or light chain variable domain, operably linked to a promoter. Such vectors may include the nucleotide sequence encoding the constant region of the antibody molecule (*see, e.g.*, international applications WO 86/05807 and WO 89/01036; and US patent no. 5,122,464) and the variable domain of the antibody may be cloned into such a vector for expression of the entire heavy or light chain.

The term "vector" or "expression vector" is used herein to mean vectors used in accordance with the present invention as a vehicle for introducing into and expressing a desired gene in a host cell. As known to those skilled in the art, such vectors may easily be selected from the group consisting of plasmids, phages, viruses and retroviruses. In general, vectors compatible with the instant invention will comprise a selection marker, appropriate restriction sites to facilitate cloning of the desired gene and the ability to enter and/or replicate in eukaryotic or prokaryotic cells. For the purposes of this invention, numerous expression vector systems may be employed. For example, one class of vector utilizes DNA elements which are derived from animal viruses such as bovine papilloma virus, polyoma virus, adenovirus, vaccinia virus, baculovirus, retroviruses (RSV, MMTV or MOMLV) or SV40 virus. Others involve the use of polycistronic systems with internal ribosome binding sites. Additionally, cells which have integrated the DNA into their chromosomes may be selected by introducing one or more markers which allow selection of transfected host cells. The marker may provide for prototrophy to an auxotrophic host, biocide resistance (*e.g.*, antibiotics) or resistance to heavy metals such as copper. The selectable marker gene can either be directly linked to the DNA sequences to be expressed, or introduced into the same cell by co-transformation. Additional elements may also be needed for optimal synthesis of mRNA. These elements may include

signal sequences, splice signals, as well as transcriptional promoters, enhancers, and termination signals.

In particularly preferred embodiments the cloned variable region genes are inserted into an expression vector along with the heavy and light chain constant region genes (preferably human) as discussed above. In one embodiment, this is effected using a proprietary expression vector of Biogen IDEC, Inc., referred to as NEOSPLA, disclosed in US patent no. 6,159,730. This vector contains the cytomegalovirus promoter/enhancer, the mouse beta globin major promoter, the SV40 origin of replication, the bovine growth hormone polyadenylation sequence, neomycin phosphotransferase exon 1 and exon 2, the dihydrofolate reductase gene and leader sequence. This vector has been found to result in very high level expression of antibodies upon incorporation of variable and constant region genes, transfection in CHO cells, followed by selection in G418 containing medium and methotrexate amplification. Of course, any expression vector which is capable of eliciting expression in eukaryotic cells may be used in the present invention. Examples of suitable vectors include, but are not limited to plasmids pcDNA3, pHCMV/Zeo, pCR3.1, pEF1/His, pIND/GS, pRc/HCMV2, pSV40/Zeo2, pTRACER-HCMV, pUB6/V5-His, pVAX1, and pZeoSV2 (available from Invitrogen, San Diego, CA), and plasmid pCI (available from Promega, Madison, WI). In general, screening large numbers of transformed cells for those which express suitably high levels if immunoglobulin heavy and light chains is routine experimentation which can be carried out, for example, by robotic systems. Vector systems are also taught in US patent nos. 5,736,137 and 5,658,570, each of which is incorporated by reference in its entirety herein. This system provides for high expression levels, *e.g.*, > 30 pg/cell/day. Other exemplary vector systems are disclosed *e.g.*, in US patent no. 6,413,777.

In other preferred embodiments the antibodies, or antigen-binding fragments, variants, or derivatives thereof of the invention may be expressed using polycistronic constructs such as those disclosed in US patent application publication no. 2003-0157641 A1 and incorporated herein in its entirety. In these expression systems, multiple gene products of interest such as heavy and light chains of antibodies may be produced from a single polycistronic construct. These systems advantageously use an internal ribosome entry site (IRES) to provide relatively high levels of antibodies. Compatible IRES sequences are disclosed in US patent no. 6,193,980 which is also incorporated herein. Those skilled in the art will appreciate that such

expression systems may be used to effectively produce the full range of antibodies disclosed in the instant application.

More generally, once the vector or DNA sequence encoding a monomeric subunit of the antibody has been prepared, the expression vector may be introduced into an appropriate host cell. Introduction of the plasmid into the host cell can be accomplished by various techniques well known to those of skill in the art. These include, but are not limited to, transfection including lipotransfection using, e.g., Fugene or lipofectamine, protoplast fusion, calcium phosphate precipitation, cell fusion with enveloped DNA, microinjection, and infection with intact virus. Typically, plasmid introduction into the host is via standard calcium phosphate co-precipitation method. The host cells harboring the expression construct are grown under conditions appropriate to the production of the light chains and heavy chains, and assayed for heavy and/or light chain protein synthesis. Exemplary assay techniques include enzyme-linked immunosorbent assay (ELISA), radioimmunoassay (RIA), or fluorescence-activated cell sorter analysis (FACS), immunohistochemistry and the like.

The expression vector is transferred to a host cell by conventional techniques and the transfected cells are then cultured by conventional techniques to produce an antibody for use in the methods described herein. Thus, the invention includes host cells containing a polynucleotide encoding an antibody of the invention, or a heavy or light chain thereof, operably linked to a heterologous promoter. In preferred embodiments for the expression of double-chained antibodies, vectors encoding both the heavy and light chains may be co-expressed in the host cell for expression of the entire immunoglobulin molecule, as detailed below.

The host cell may be co-transfected with two expression vectors of the invention, the first vector encoding a heavy chain derived polypeptide and the second vector encoding a light chain derived polypeptide. The two vectors may contain identical selectable markers which enable equal expression of heavy and light chain polypeptides. Alternatively, a single vector may be used which encodes both heavy and light chain polypeptides. In such situations, the light chain is advantageously placed before the heavy chain to avoid an excess of toxic free heavy chain; *see* Proudfoot, Nature 322 (1986), 52; Kohler, Proc. Natl. Acad. Sci. USA 77

(1980), 2197. The coding sequences for the heavy and light chains may comprise cDNA or genomic DNA.

As used herein, "host cells" refers to cells which harbor vectors constructed using recombinant DNA techniques and encoding at least one heterologous gene. In descriptions of processes for isolation of antibodies from recombinant hosts, the terms "cell" and "cell culture" are used interchangeably to denote the source of antibody unless it is clearly specified otherwise. In other words, recovery of polypeptide from the "cells" may mean either from spun down whole cells, or from the cell culture containing both the medium and the suspended cells.

A variety of host-expression vector systems may be utilized to express antibody molecules for use in the methods described herein. Such host-expression systems represent vehicles by which the coding sequences of interest may be produced and subsequently purified, but also represent cells which may, when transformed or transfected with the appropriate nucleotide coding sequences, express an antibody molecule of the invention *in situ*. These include but are not limited to microorganisms such as bacteria (*e.g.*, *E. coli*, *B. subtilis*) transformed with recombinant bacteriophage DNA, plasmid DNA or cosmid DNA expression vectors containing antibody coding sequences; yeast (*e.g.*, *Saccharomyces*, *Pichia*) transformed with recombinant yeast expression vectors containing antibody coding sequences; insect cell systems infected with recombinant virus expression vectors (*e.g.*, baculovirus) containing antibody coding sequences; plant cell systems infected with recombinant virus expression vectors (*e.g.*, cauliflower mosaic virus, CaMV; tobacco mosaic virus, TMV) or transformed with recombinant plasmid expression vectors (*e.g.*, Ti plasmid) containing antibody coding sequences; or mammalian cell systems (*e.g.*, COS, CHO, NSO, BLK, 293, 3T3 cells) harboring recombinant expression constructs containing promoters derived from the genome of mammalian cells (*e.g.*, metallothionein promoter) or from mammalian viruses (*e.g.*, the adenovirus late promoter; the vaccinia virus 7.5K promoter). Preferably, bacterial cells such as *Escherichia coli*, and more preferably, eukaryotic cells, especially for the expression of whole recombinant antibody molecule, are used for the expression of a recombinant antibody molecule. For example, mammalian cells such as Chinese Hamster Ovary (CHO) cells, in conjunction with a vector such as the major intermediate early gene promoter element from

human cytomegalovirus is an effective expression system for antibodies; *see, e.g.*, Foecking *et al.*, Gene 45 (1986), 101; Cockett *et al.*, Bio/Technology 8 (1990), 2.

The host cell line used for protein expression is often of mammalian origin; those skilled in the art are credited with ability to preferentially determine particular host cell lines which are best suited for the desired gene product to be expressed therein. Exemplary host cell lines include, but are not limited to, CHO (Chinese Hamster Ovary), DG44 and DUXB11 (Chinese Hamster Ovary lines, DHFR minus), HELA (human cervical carcinoma), CVI (monkey kidney line), COS (a derivative of CVI with SV40 T antigen), VERY, BHK (baby hamster kidney), MDCK, WI38, R1610 (Chinese hamster fibroblast) BALBC/3T3 (mouse fibroblast), HAK (hamster kidney line), SP2/O (mouse myeloma), P3x63-Ag3.653 (mouse myeloma), BFA-1c1BPT (bovine endothelial cells), RAJI (human lymphocyte) and 293 (human kidney). CHO and 293 cells are particularly preferred. Host cell lines are typically available from commercial services, the American Tissue Culture Collection or from published literature.

In addition, a host cell strain may be chosen which modulates the expression of the inserted sequences, or modifies and processes the gene product in the specific fashion desired. Such modifications (*e.g.*, glycosylation) and processing (*e.g.*, cleavage) of protein products may be important for the function of the protein. Different host cells have characteristic and specific mechanisms for the post-translational processing and modification of proteins and gene products. Appropriate cell lines or host systems can be chosen to ensure the correct modification and processing of the foreign protein expressed. To this end, eukaryotic host cells which possess the cellular machinery for proper processing of the primary transcript, glycosylation, and phosphorylation of the gene product may be used.

For long-term, high-yield production of recombinant proteins, stable expression is preferred. For example, cell lines which stably express the antibody molecule may be engineered. Rather than using expression vectors which contain viral origins of replication, host cells can be transformed with DNA controlled by appropriate expression control elements (*e.g.*, promoter, enhancer, sequences, transcription terminators, polyadenylation sites, etc.), and a selectable marker. Following the introduction of the foreign DNA, engineered cells may be allowed to grow for 1-2 days in an enriched media, and then are switched to a selective media. The selectable marker in the recombinant plasmid confers resistance to the selection

and allows cells to stably integrate the plasmid into their chromosomes and grow to form foci which in turn can be cloned and expanded into cell lines. This method may advantageously be used to engineer cell lines which stably express the antibody molecule.

A number of selection systems may be used, including but not limited to the herpes simplex virus thymidine kinase (Wigler *et al.*, Cell 11 (1977), 223), hypoxanthine-guanine phosphoribosyltransferase (Szybalska & Szybalski, Proc. Natl. Acad. Sci. USA 48 (1992), 202), and adenine phosphoribosyltransferase (Lowy *et al.*, Cell 22 (1980), 817) genes can be employed in tk-, hgprt- or aprt-cells, respectively. Also, anti-metabolite resistance can be used as the basis of selection for the following genes: dhfr, which confers resistance to methotrexate (Wigler *et al.*, Natl. Acad. Sci. USA 77 (1980), 357; O'Hare *et al.*, Proc. Natl. Acad. Sci. USA 78 (1981), 1527); gpt, which confers resistance to mycophenolic acid (Mulligan & Berg, Proc. Natl. Acad. Sci. USA 78 (1981), 2072); neo, which confers resistance to the aminoglycoside G-418 Goldspiel *et al.*, Clinical Pharmacy 12 (1993), 488-505; Wu and Wu, Biotherapy 3 (1991), 87-95; Tolstoshev, Ann. Rev. Pharmacol. Toxicol. 32 (1993), 573-596; Mulligan, Science 260 (1993), 926-932; and Morgan and Anderson, Ann. Rev. Biochem. 62 (1993), 191-217; TIB TECH 11 (1993), 155-215; and hygro, which confers resistance to hygromycin (Santerre *et al.*, Gene 30 (1984), 147. Methods commonly known in the art of recombinant DNA technology which can be used are described in Ausubel *et al.* (eds.), *Current Protocols in Molecular Biology*, John Wiley & Sons, NY (1993); Kriegler, *Gene Transfer and Expression*, A Laboratory Manual, Stockton Press, NY (1990); and in Chapters 12 and 13, Dracopoli *et al.* (eds), *Current Protocols in Human Genetics*, John Wiley & Sons, NY (1994); Colberre-Garapin *et al.*, J. Mol. Biol. 150:1 (1981), which are incorporated by reference herein in their entireties.

The expression levels of an antibody molecule can be increased by vector amplification, for a review, see Bebbington and Hentschel, *The use of vectors based on gene amplification for the expression of cloned genes in mammalian cells in DNA cloning*, Academic Press, New York, Vol. 3. (1987). When a marker in the vector system expressing antibody is amplifiable, increase in the level of inhibitor present in culture of host cell will increase the number of copies of the marker gene. Since the amplified region is associated with the antibody gene, production of the antibody will also increase; see Crouse *et al.*, Mol. Cell. Biol. 3 (1983), 257.

In vitro production allows scale-up to give large amounts of the desired polypeptides. Techniques for mammalian cell cultivation under tissue culture conditions are known in the art and include homogeneous suspension culture, *e.g.* in an airlift reactor or in a continuous stirrer reactor, or immobilized or entrapped cell culture, *e.g.* in hollow fibers, microcapsules, on agarose microbeads or ceramic cartridges. If necessary and/or desired, the solutions of polypeptides can be purified by the customary chromatography methods, for example gel filtration, ion-exchange chromatography, chromatography over DEAE-cellulose or (immuno-)affinity chromatography, *e.g.*, after preferential biosynthesis of a synthetic hinge region polypeptide or prior to or subsequent to the HIC chromatography step described herein.

Genes encoding antibodies, or antigen-binding fragments, variants, or derivatives thereof of the invention can also be expressed in non-mammalian cells such as bacteria or insect or yeast or plant cells. Bacteria which readily take up nucleic acids include members of the enterobacteriaceae, such as strains of *Escherichia coli* or *Salmonella*; Bacillaceae, such as *Bacillus subtilis*; *Pneumococcus*; *Streptococcus*, and *Haemophilus influenzae*. It will further be appreciated that, when expressed in bacteria, the heterologous polypeptides typically become part of inclusion bodies. The heterologous polypeptides must be isolated, purified and then assembled into functional molecules. Where tetravalent forms of antibodies are desired, the subunits will then self-assemble into tetravalent antibodies; *see, e.g.*, international application WO02/096948.

In bacterial systems, a number of expression vectors may be advantageously selected depending upon the use intended for the antibody molecule being expressed. For example, when a large quantity of such a protein is to be produced, for the generation of pharmaceutical compositions of an antibody molecule, vectors which direct the expression of high levels of fusion protein products that are readily purified may be desirable. Such vectors include, but are not limited, to the *E. coli* expression vector pUR278 (Ruther *et al.*, EMBO J. 2 (1983), 1791), in which the antibody coding sequence may be ligated individually into the vector in frame with the lacZ coding region so that a fusion protein is produced; pIN vectors (Inouye & Inouye, Nucleic Acids Res. 13 (1985), 3101-3109; Van Heeke & Schuster, J. Biol. Chem. 24 (1989), 5503-5509); and the like. pGEX vectors may also be used to express foreign polypeptides as fusion proteins with glutathione S-transferase (GST). In general, such fusion proteins are soluble and can easily be purified from lysed cells by adsorption and binding to a

matrix of glutathione-agarose beads followed by elution in the presence of free glutathione. The pGEX vectors are designed to include thrombin or factor Xa protease cleavage sites so that the cloned target gene product can be released from the GST moiety.

In addition to prokaryotes, eukaryotic microbes may also be used. *Saccharomyces cerevisiae*, or common baker's yeast, is the most commonly used among eukaryotic microorganisms although a number of other strains are commonly available, *e.g.*, *Pichia pastoris*. For expression in *Saccharomyces*, the plasmid YRp7, for example, (Stinchcomb *et al.*, Nature 282 (1979), 39; Kingsman *et al.*, Gene 7 (1979), 141; Tschemper *et al.*, Gene 10 (1980), 157) is commonly used. This plasmid already contains the TRP1 gene which provides a selection marker for a mutant strain of yeast lacking the ability to grow in tryptophan, for example ATCC No. 44076 or PEP4-1 (Jones, Genetics 85 (1977), 12). The presence of the trp1 lesion as a characteristic of the yeast host cell genome then provides an effective environment for detecting transformation by growth in the absence of tryptophan.

In an insect system, *Autographa californica* nuclear polyhedrosis virus (AcNPV) is typically used as a vector to express foreign genes. The virus grows in Spodoptera *frugiperda* cells. The antibody coding sequence may be cloned individually into non-essential regions (for example the polyhedrin gene) of the virus and placed under control of an AcNPV promoter (for example the polyhedrin promoter).

Once an antibody molecule of the invention has been recombinantly expressed, the whole antibodies, their dimers, individual light and heavy chains, or other immunoglobulin forms of the present invention, can be purified according to standard procedures of the art, including for example, by chromatography (*e.g.*, ion exchange, affinity, particularly by affinity for the specific antigen after Protein A, and sizing column chromatography), centrifugation, differential solubility, *e.g.* ammonium sulfate precipitation, or by any other standard technique for the purification of proteins; see, *e.g.*, Scopes, "Protein Purification", Springer Verlag, N.Y. (1982). Alternatively, a preferred method for increasing the affinity of antibodies of the invention is disclosed in US patent publication 2002-0123057 A1.

V. **Fusion Proteins and Conjugates**

In certain embodiments, the antibody polypeptide comprises an amino acid sequence or one or more moieties not normally associated with an antibody. Exemplary modifications are described in more detail below. For example, a single-chain fv antibody fragment of the invention may comprise a flexible linker sequence, or may be modified to add a functional moiety (*e.g.*, PEG, a drug, a toxin, or a label such as a fluorescent, radioactive, enzyme, nuclear magnetic, heavy metal and the like)

An antibody polypeptide of the invention may comprise, consist essentially of, or consist of a fusion protein. Fusion proteins are chimeric molecules which comprise, for example, an immunoglobulin α-synuclein-binding domain with at least one target binding site, and at least one heterologous portion, *i.e.*, a portion with which it is not naturally linked in nature. The amino acid sequences may normally exist in separate proteins that are brought together in the fusion polypeptide or they may normally exist in the same protein but are placed in a new arrangement in the fusion polypeptide. Fusion proteins may be created, for example, by chemical synthesis, or by creating and translating a polynucleotide in which the peptide regions are encoded in the desired relationship.

The term "heterologous" as applied to a polynucleotide or a polypeptide, means that the polynucleotide or polypeptide is derived from a distinct entity from that of the rest of the entity to which it is being compared. For instance, as used herein, a "heterologous polypeptide" to be fused to an antibody, or an antigen-binding fragment, variant, or analog thereof is derived from a non-immunoglobulin polypeptide of the same species, or an immunoglobulin or non-immunoglobulin polypeptide of a different species.

As discussed in more detail elsewhere herein, antibodies, or antigen-binding fragments, variants, or derivatives thereof of the invention may further be recombinantly fused to a heterologous polypeptide at the N- or C-terminus or chemically conjugated (including covalent and non-covalent conjugations) to polypeptides or other compositions. For example, antibodies may be recombinantly fused or conjugated to molecules useful as labels in detection assays and effector molecules such as heterologous polypeptides, drugs, radionuclides, or toxins; *see*, *e.g.*, international applications WO92/08495; WO91/14438; WO89/12624; US patent no. 5,314,995; and European patent application EP 0 396 387.

Antibodies, or antigen-binding fragments, variants, or derivatives thereof of the invention can be composed of amino acids joined to each other by peptide bonds or modified peptide bonds, *i.e.*, peptide isosteres, and may contain amino acids other than the 20 gene-encoded amino acids. Antibodies may be modified by natural processes, such as posttranslational processing, or by chemical modification techniques which are well known in the art. Such modifications are well described in basic texts and in more detailed monographs, as well as in a voluminous research literature. Modifications can occur anywhere in the antibody, including the peptide backbone, the amino acid side-chains and the amino or carboxyl termini, or on moieties such as carbohydrates. It will be appreciated that the same type of modification may be present in the same or varying degrees at several sites in a given antibody. Also, a given antibody may contain many types of modifications. Antibodies may be branched, for example, as a result of ubiquitination, and they may be cyclic, with or without branching. Cyclic, branched, and branched cyclic antibodies may result from posttranslation natural processes or may be made by synthetic methods. Modifications include acetylation, acylation, ADP-ribosylation, amidation, covalent attachment of flavin, covalent attachment of a heme moiety, covalent attachment of a nucleotide or nucleotide derivative, covalent attachment of a lipid or lipid derivative, covalent attachment of phosphotidylinositol, cross-linking, cyclization, disulfide bond formation, demethylation, formation of covalent cross-links, formation of cysteine, formation of pyroglutamate, formylation, gamma-carboxylation, glycosylation, GPI anchor formation, hydroxylation, iodination, methylation, myristoylation, oxidation, pegylation, proteolytic processing, phosphorylation, prenylation, racemization, selenoylation, sulfation, transfer-RNA mediated addition of amino acids to proteins such as arginylation, and ubiquitination; *see, e.g., Proteins - Structure And Molecular Properties*, T. E. Creighton, W. H. Freeman and Company, New York 2nd Ed., (1993); *Posttranslational Covalent Modification Of Proteins*, B. C. Johnson, Ed., Academic Press, New York, pgs. 1-12 (1983); Seifter *et al.*, Meth. Enzymol. 182 (1990), 626-646; Rattan *et al.*, Ann. NY Acad. Sci. 663 (1992), 48-62).

The present invention also provides for fusion proteins comprising an antibody, or antigen-binding fragment, variant, or derivative thereof, and a heterologous polypeptide. In one embodiment, a fusion protein of the invention comprises, consists essentially of, or consists of, a polypeptide having the amino acid sequence of any one or more of the V_H regions of an antibody of the invention or the amino acid sequence of any one or more of the V_L regions of

an antibody of the invention or fragments or variants thereof, and a heterologous polypeptide sequence. In another embodiment, a fusion protein for use in the diagnostic and treatment methods disclosed herein comprises, consists essentially of, or consists of a polypeptide having the amino acid sequence of any one, two, three of the V_H-CDRs of an antibody, or fragments, variants, or derivatives thereof, or the amino acid sequence of any one, two, three of the V_L-CDRs of an antibody, or fragments, variants, or derivatives thereof, and a heterologous polypeptide sequence. In one embodiment, the fusion protein comprises a polypeptide having the amino acid sequence of a V_H-CDR3 of an antibody of the present invention, or fragment, derivative, or variant thereof, and a heterologous polypeptide sequence, which fusion protein specifically binds to α-synuclein. In another embodiment, a fusion protein comprises a polypeptide having the amino acid sequence of at least one V_H region of an antibody of the invention and the amino acid sequence of at least one V_L region of an antibody of the invention or fragments, derivatives or variants thereof, and a heterologous polypeptide sequence. Preferably, the V_H and V_L regions of the fusion protein correspond to a single source antibody (or scFv or Fab fragment) which specifically binds α-synuclein. In yet another embodiment, a fusion protein for use in the diagnostic and treatment methods disclosed herein comprises a polypeptide having the amino acid sequence of any one, two, three or more of the V_H CDRs of an antibody and the amino acid sequence of any one, two, three or more of the V_L CDRs of an antibody, or fragments or variants thereof, and a heterologous polypeptide sequence. Preferably, two, three, four, five, six, or more of the V_H-CDR(s) or V_L-CDR(s) correspond to single source antibody (or scFv or Fab fragment) of the invention. Nucleic acid molecules encoding these fusion proteins are also encompassed by the invention.

Exemplary fusion proteins reported in the literature include fusions of the T cell receptor (Gascoigne *et al.*, Proc. Natl. Acad. Sci. USA 84 (1987), 2936-2940; CD4 (Capon *et al.*, Nature 337 (1989), 525-531; Traunecker *et al.*, Nature 339 (1989), 68-70; Zettmeissl *et al.*, DNA Cell Biol. USA 9 (1990), 347-353; and Byrn *et al.*, Nature 344 (1990), 667-670); L-selectin (homing receptor) (Watson *et al.*, J. Cell. Biol. 110 (1990), 2221-2229; and Watson *et al.*, Nature 349 (1991), 164-167); CD44 (Aruffo *et al.*, Cell 61 (1990), 1303-1313); CD28 and B7 (Linsley *et al.*, J. Exp. Med. 173 (1991),721-730); CTLA-4 (Lisley *et al.*, J. Exp. Med. 174 (1991), 561-569); CD22 (Stamenkovic *et al.*, Cell 66 (1991), 1133-1144); TNF receptor (Ashkenazi *et al.*, Proc. Natl. Acad. Sci. USA 88 (1991), 10535-10539; Lesslauer *et al.*, Eur.

J. Immunol. 27 (1991), 2883-2886; and Peppel *et al.*, J. Exp. Med. 174 (1991), 1483-1489 (1991); and IgE receptor a (Ridgway and Gorman, J. Cell. Biol. 115 (1991), Abstract No. 1448).

As discussed elsewhere herein, antibodies, or antigen-binding fragments, variants, or derivatives thereof of the invention may be fused to heterologous polypeptides to increase the in vivo half life of the polypeptides or for use in immunoassays using methods known in the art. For example, in one embodiment, PEG can be conjugated to the antibodies of the invention to increase their half-life in vivo; see, *e.g.*, Leong *et al.*, Cytokine 16 (2001), 106-119; Adv. in Drug Deliv. Rev. 54 (2002), 531; or Weir *et al.*, Biochem. Soc. Transactions 30 (2002), 512.

Moreover, antibodies, or antigen-binding fragments, variants, or derivatives thereof of the invention can be fused to marker sequences, such as a peptide to facilitate their purification or detection. In preferred embodiments, the marker amino acid sequence is a hexa-histidine peptide (HIS), such as the tag provided in a pQE vector (QIAGEN, Inc., 9259 Eton Avenue, Chatsworth, Calif., 91311), among others, many of which are commercially available. As described in Gentz *et al.*, Proc. Natl. Acad. Sci. USA 86 (1989), 821-824, for instance, hexa-histidine provides for convenient purification of the fusion protein. Other peptide tags useful for purification include, but are not limited to, the "HA" tag, which corresponds to an epitope derived from the influenza hemagglutinin protein (Wilson *et al.*, Cell 37 (1984), 767) and the "flag" tag.

Fusion proteins can be prepared using methods that are well known in the art; *see* for example US patent nos. 5,116,964 and 5,225,538. The precise site at which the fusion is made may be selected empirically to optimize the secretion or binding characteristics of the fusion protein. DNA encoding the fusion protein is then transfected into a host cell for expression.

Antibodies of the present invention may be used in non-conjugated form or may be conjugated to at least one of a variety of molecules, *e.g.*, to improve the therapeutic properties of the molecule, to facilitate target detection, or for imaging or therapy of the patient. Antibodies, or antigen-binding fragments, variants, or derivatives thereof of the invention can be labeled or conjugated either before or after purification, when purification is performed. In

particular, antibodies, or antigen-binding fragments, variants, or derivatives thereof of the invention may be conjugated to therapeutic agents, prodrugs, peptides, proteins, enzymes, viruses, lipids, biological response modifiers, pharmaceutical agents, or PEG.

Conjugates that are immunotoxins including conventional antibodies have been widely described in the art. The toxins may be coupled to the antibodies by conventional coupling techniques or immunotoxins containing protein toxin portions can be produced as fusion proteins. The antibodies of the present invention can be used in a corresponding way to obtain such immunotoxins. Illustrative of such immunotoxins are those described by Byers, Seminars Cell. Biol. 2 (1991), 59-70 and by Fanger, Immunol. Today 12 (1991), 51-54.

Those skilled in the art will appreciate that conjugates may also be assembled using a variety of techniques depending on the selected agent to be conjugated. For example, conjugates with biotin are prepared *e.g.* by reacting an α-synuclein binding polypeptide with an activated ester of biotin such as the biotin N-hydroxysuccinimide ester. Similarly, conjugates with a fluorescent marker may be prepared in the presence of a coupling agent, *e.g.* those listed herein, or by reaction with an isothiocyanate, preferably fluorescein-isothiocyanate. Conjugates of the antibodies, or antigen-binding fragments, variants, or derivatives thereof of the invention are prepared in an analogous manner.

The present invention further encompasses antibodies, or antigen-binding fragments, variants, or derivatives thereof of the invention conjugated to a diagnostic or therapeutic agent. The antibodies can be used diagnostically to, for example, demonstrate presence of a neurological disease, to indicate the risk of getting a neurological disease, to monitor the development or progression of a neurological disease, *i.e.* synucleinopathic disease as part of a clinical testing procedure to, *e.g.*, determine the efficacy of a given treatment and/or prevention regimen. Detection can be facilitated by coupling the antibody, or antigen-binding fragment, variant, or derivative thereof to a detectable substance. Examples of detectable substances include various enzymes, prosthetic groups, fluorescent materials, luminescent materials, bioluminescent materials, radioactive materials, positron emitting metals using various positron emission tomographies, and nonradioactive paramagnetic metal ions; *see, e.g.*, US patent no. 4,741,900 for metal ions which can be conjugated to antibodies for use as diagnostics according to the present invention. Examples of suitable enzymes include

horseradish peroxidase, alkaline phosphatase, β-galactosidase, or acetylcholinesterase; examples of suitable prosthetic group complexes include streptavidin/biotin and avidin/biotin; examples of suitable fluorescent materials include umbelliferone, fluorescein, fluorescein isothiocyanate, rhodamine, dichlorotriazinylamine fluorescein, dansyl chloride or phycoerythrin; an example of a luminescent material includes luminol; examples of bioluminescent materials include luciferase, luciferin, and aequorin; and examples of suitable radioactive material include ^{125}I, ^{131}I, ^{111}In or ^{99}Tc.

An antibody, or antigen-binding fragment, variant, or derivative thereof also can be detectably labeled by coupling it to a chemiluminescent compound. The presence of the chemiluminescent-tagged antibody is then determined by detecting the presence of luminescence that arises during the course of a chemical reaction. Examples of particularly useful chemiluminescent labeling compounds are luminol, isoluminol, theromatic acridinium ester, imidazole, acridinium salt and oxalate ester.

One of the ways in which an antibody, or antigen-binding fragment, variant, or derivative thereof can be detectably labeled is by linking the same to an enzyme and using the linked product in an enzyme immunoassay (EIA) (Voller, A., "The Enzyme Linked Immunosorbent Assay (ELISA)" Microbiological Associates Quarterly Publication, Walkersville, Md., Diagnostic Horizons 2 (1978), 1-7); Voller *et al.*, J. Clin. Pathol. 31 (1978), 507-520; Butler, Meth. Enzymol. 73 (1981), 482-523; Maggio, E. (ed.), *Enzyme Immunoassay*, CRC Press, Boca Raton, Fla., (1980); Ishikawa, E. *et al.*, (eds.), *Enzyme Immunoassay*, Kgaku Shoin, Tokyo (1981). The enzyme, which is bound to the antibody will react with an appropriate substrate, preferably a chromogenic substrate, in such a manner as to produce a chemical moiety which can be detected, for example, by spectrophotometric, fluorimetric or by visual means. Enzymes which can be used to detectably label the antibody include, but are not limited to, malate dehydrogenase, staphylococcal nuclease, delta-5-steroid isomerase, yeast alcohol dehydrogenase, alpha-glycerophosphate, dehydrogenase, triose phosphate isomerase, horseradish peroxidase, alkaline phosphatase, asparaginase, glucose oxidase, beta-galactosidase, ribonuclease, urease, catalase, glucose-6-phosphate dehydrogenase, glucoamylase and acetylcholinesterase. Additionally, the detection can be accomplished by colorimetric methods which employ a chromogenic substrate for the enzyme. Detection may

also be accomplished by visual comparison of the extent of enzymatic reaction of a substrate in comparison with similarly prepared standards.

Detection may also be accomplished using any of a variety of other immunoassays. For example, by radioactively labeling the antibody, or antigen-binding fragment, variant, or derivative thereof, it is possible to detect the antibody through the use of a radioimmunoassay (RIA) (*see*, for example, Weintraub, B., *Principles of Radioimmunoassays, Seventh Training Course on Radioligand Assay Techniques*, The Endocrine Society, (March, 1986)), which is incorporated by reference herein). The radioactive isotope can be detected by means including, but not limited to, a gamma counter, a scintillation counter, or autoradiography.

An antibody, or antigen-binding fragment, variant, or derivative thereof can also be detectably labeled using fluorescence emitting metals such as ^{152}Eu, or others of the lanthanide series. These metals can be attached to the antibody using such metal chelating groups as diethylenetriaminepentacetic acid (DTPA) or ethylenediaminetetraacetic acid (EDTA).

Techniques for conjugating various moieties to an antibody, or antigen-binding fragment, variant, or derivative thereof are well known, *see, e.g.*, Arnon *et al.*, "Monoclonal Antibodies For Immunotargeting Of Drugs In Cancer Therapy", in *Monoclonal Antibodies And Cancer Therapy*, Reisfeld *et al.* (eds.), pp. 243-56 (Alan R. Liss, Inc. (1985); Hellstrom *et al.*, "Antibodies For Drug Delivery", in *Controlled Drug Delivery* (2nd Ed.), Robinson *et al.* (eds.), Marcel Dekker, Inc., pp. 623-53 (1987); Thorpe, "Antibody Carriers Of Cytotoxic Agents In Cancer Therapy: A Review", in *Monoclonal Antibodies '84: Biological And Clinical Applications*, Pinchera *et al.* (eds.), pp. 475-506 (1985); "Analysis, Results, And Future Prospective Of The Therapeutic Use Of Radiolabeled Antibody In Cancer Therapy", in *Monoclonal Antibodies For Cancer Detection And Therapy*, Baldwin *et al.* (eds.), Academic Press pp. 303-16 (1985), and Thorpe *et al.*, "The Preparation And Cytotoxic Properties Of Antibody-Toxin Conjugates", Immunol. Rev. 62 (1982), 119-158.

As mentioned, in certain embodiments, a moiety that enhances the stability or efficacy of a binding molecule, *e.g.*, a binding polypeptide, *e.g.*, an antibody or immunospecific fragment thereof can be conjugated. For example, in one embodiment, PEG can be conjugated to the binding molecules of the invention to increase their half-life *in vivo*. Leong *et al.*, Cytokine 16

(2001), 106; Adv. in Drug Deliv. Rev. 54 (2002), 531; or Weir *et al.*, Biochem. Soc. Transactions 30 (2002), 512.

VI. Compositions and Methods of Use

The present invention relates to compositions comprising the aforementioned α-synuclein binding molecule, *e.g.*, antibody or antigen-binding fragment thereof of the present invention or derivative or variant thereof, or the polynucleotide, vector or cell of the invention. The composition of the present invention may further comprise a pharmaceutically acceptable carrier. Furthermore, the pharmaceutical composition of the present invention may comprise further agents such as interleukins or interferons depending on the intended use of the pharmaceutical composition. For example, for use in the treatment of Parkinson's disease the additional agent may be selected from the group consisting of small organic molecules, anti-α-synuclein antibodies, and combinations thereof. Hence, in a particular preferred embodiment the present invention relates to the use of the α-synuclein binding molecule, *e.g.*, antibody or antigen-binding fragment thereof of the present invention or of a binding molecule having substantially the same binding specificities of any one thereof, the polynucleotide, the vector or the cell of the present invention for the preparation of a pharmaceutical or diagnostic composition for prophylactic and therapeutic treatment of a synucleinopathic disease, monitoring the progression of a synucleinopathic disease or a response to a synucleinopathic disease treatment in a subject or for determining a subject's risk for developing a synucleinopathic disease.

Hence, in one embodiment the present invention relates to a method of treating a neurological disorder characterized by abnormal accumulation and/or deposition of α-synuclein in the brain and the central nervous system, respectively, which method comprises administering to a subject in need thereof a therapeutically effective amount of any one of the afore-described α-synuclein binding molecules, antibodies, polynucleotides, vectors or cells of the instant invention. The term "neurological disorder" includes but is not limited to synucleinopathic diseases such as Parkinson's disease (PD), Parkinson's disease dementia (PDD), dementia with Lewy bodies (DLB), the Lewy body variant of Alzheimer's disease (LBVAD), multiple systems atrophy (MSA), pure autonomic failure (PAF), neurodegeneration with brain iron accumulation type-1 (NBIA-I), Alzheimer's disease, Pick disease, juvenile-onset generalized neuroaxonal dystrophy (Hallervorden-Spatz disease), amyotrophic lateral sclerosis, traumatic

brain injury, and Down syndrome as well as other movement disorders and disease of the central nervous system (CNS) in general. Unless stated otherwise, the terms neurodegenerative, neurological or neuropsychiatric are used interchangeably herein.

A particular advantage of the therapeutic approach of the present invention lies in the fact that the antibodies of the present invention are derived from B cells or B memory cells from elderly subjects with no signs of Parkinsonism and thus are, with a certain probability, capable of preventing a clinically manifest synucleinopathic disease, or of diminishing the risk of the occurrence of the clinically manifest disease, or of delaying the onset or progression of the clinically manifest disease. Typically, the antibodies of the present invention also have already successfully gone through somatic maturation, *i.e.* the optimization with respect to selectivity and effectiveness in the high affinity binding to the target α-synuclein molecule by means of somatic variation of the variable regions of the antibody.

The knowledge that such cells *in vivo*, *e.g.* in a human, have not been activated by means of related or other physiological proteins or cell structures in the sense of an autoimmunological or allergic reaction is also of great medical importance since this signifies a considerably increased chance of successfully living through the clinical test phases. So to speak, efficiency, acceptability and tolerability have already been demonstrated before the preclinical and clinical development of the prophylactic or therapeutic antibody in at least one human subject. It can thus be expected that the human anti-α-synuclein antibodies of the present invention, both its target structure-specific efficiency as therapeutic agent and its decreased probability of side effects significantly increase its clinical probability of success.

The present invention also provides a pharmaceutical and diagnostic, respectively, pack or kit comprising one or more containers filled with one or more of the above described ingredients, *e.g.* anti-α-synuclein antibody, binding fragment, derivative or variant thereof, polynucleotide, vector or cell of the present invention. Associated with such container(s) can be a notice in the form prescribed by a governmental agency regulating the manufacture, use or sale of pharmaceuticals or biological products, which notice reflects approval by the agency of manufacture, use or sale for human administration. In addition or alternatively the kit comprises reagents and/or instructions for use in appropriate diagnostic assays. The

composition, *e.g.* kit of the present invention is of course particularly suitable for the risk assessment, diagnosis, prevention and treatment of a disorder which is accompanied with the presence of α-synuclein, and in particular applicable for the treatment of Parkinson's disease (PD), Parkinson's disease dementia (PDD), dementia with Lewy bodies (DLB) and Lewy body variant of Alzheimer's disease (LBVAD).

The pharmaceutical compositions of the present invention can be formulated according to methods well known in the art; see for example Remington: The Science and Practice of Pharmacy (2000) by the University of Sciences in Philadelphia, ISBN 0-683-306472. Examples of suitable pharmaceutical carriers are well known in the art and include phosphate buffered saline solutions, water, emulsions, such as oil/water emulsions, various types of wetting agents, sterile solutions etc. Compositions comprising such carriers can be formulated by well known conventional methods. These pharmaceutical compositions can be administered to the subject at a suitable dose. Administration of the suitable compositions may be effected by different ways, *e.g.*, by intravenous, intraperitoneal, subcutaneous, intramuscular, intranasal, topical or intradermal administration or spinal or brain delivery. Aerosol formulations such as nasal spray formulations include purified aqueous or other solutions of the active agent with preservative agents and isotonic agents. Such formulations are preferably adjusted to a pH and isotonic state compatible with the nasal mucous membranes. Formulations for rectal or vaginal ad-ministration may be presented as a suppository with a suitable carrier.

Furthermore, whereas the present invention includes the now standard (though fortunately infrequent) procedure of drilling a small hole in the skull to administer a drug of the present invention, in a preferred aspect, the binding molecule, especially antibody or antibody based drug of the present invention can cross the blood-brain barrier, which allows for intravenous or oral administration.

The dosage regimen will be determined by the attending physician and clinical factors. As is well known in the medical arts, dosages for any one patient depends upon many factors, including the patient's size, body surface area, age, the particular compound to be administered, sex, time and route of administration, general health, and other drugs being administered concurrently. A typical dose can be, for example, in the range of 0.001 to 1000

μg (or of nucleic acid for expression or for inhibition of expression in this range); however, doses below or above this exemplary range are envisioned, especially considering the aforementioned factors. Generally, the dosage can range, *e.g.*, from about 0.0001 to 100 mg/kg, and more usually 0.01 to 5 mg/kg (*e.g.*, 0.02 mg/kg, 0.25 mg/kg, 0.5 mg/kg, 0.75 mg/kg, 1 mg/kg, 2 mg/kg, etc.), of the host body weight. For example dosages can be 1 mg/kg body weight or 10 mg/kg body weight or within the range of 1-10 mg/kg, preferably at least 1 mg/kg. Doses intermediate in the above ranges are also intended to be within the scope of the invention. Subjects can be administered such doses daily, on alternative days, weekly or according to any other schedule determined by empirical analysis. An exemplary treatment entails administration in multiple dosages over a prolonged period, for example, of at least six months. Additional exemplary treatment regimes entail administration once per every two weeks or once a month or once every 3 to 6 months. Exemplary dosage schedules include 1-10 mg/kg or 15 mg/kg on consecutive days, 30 mg/kg on alternate days or 60 mg/kg weekly. In some methods, two or more monoclonal antibodies with different binding specificities are administered simultaneously, in which case the dosage of each antibody administered falls within the ranges indicated. Progress can be monitored by periodic assessment. Preparations for parenteral administration include sterile aqueous or non-aqueous solutions, suspensions, and emulsions. Examples of non-aqueous solvents are propylene glycol, polyethylene glycol, vegetable oils such as olive oil, and injectable organic esters such as ethyl oleate. Aqueous carriers include water, alcoholic/aqueous solutions, emulsions or suspensions, including saline and buffered media. Parenteral vehicles include sodium chloride solution, Ringer's dextrose, dextrose and sodium chloride, lactated Ringer's, or fixed oils. Intravenous vehicles include fluid and nutrient replenishers, electrolyte replenishers (such as those based on Ringer's dextrose), and the like. Preservatives and other additives may also be present such as, for example, antimicrobials, anti-oxidants, chelating agents, and inert gases and the like. Furthermore, the pharmaceutical composition of the invention may comprise further agents such as dopamine or psychopharmacologic drugs, depending on the intended use of the pharmaceutical composition.

Furthermore, in a preferred embodiment of the present invention the pharmaceutical composition may be formulated as a vaccine, for example, if the pharmaceutical composition of the invention comprises an anti-α-synuclein antibody or binding fragment, derivative or variant thereof for passive immunization. As mentioned in the background section, oligomeric

species of α-synuclein have been reported extracellularly in plasma and CSF (El-Agnaf *et al.*, FASEB J. 20 (2006), 419–425) and passive immunization studies in mouse models of Parkinson's disease show that extracellular mouse monoclonal antibodies against α-synuclein can reduce accumulation of intracellular α-synuclein aggregates (Masliah *et al.*, Neuron, 46 (2005), 857–868). Accordingly it is prudent to expect that the human anti-α-synuclein antibodies and equivalent α-synuclein binding molecules of the present invention are particularly useful as a vaccine for the prevention or amelioration of synucleinopathic diseases such as PD, DLB and LBVAD.

In one embodiment, it may be beneficial to use recombinant Fab (rFab) and single chain fragments (scFvs) of the antibody of the present invention, which might more readily penetrate a cell membrane. For example, Robert *et al.*, Protein Eng. Des. Sel. (2008) Oct 16; S1741-0134, published online ahead, describe the use of chimeric recombinant Fab (rFab) and single chain fragments (scFvs) of monoclonal antibody WO-2 which recognizes an epitope in the N-terminal region of Aβ. The engineered fragments were able to (i) prevent amyloid fibrillization, (ii) disaggregate preformed Aβ1-42 fibrils and (iii) inhibit Aβ1-42 oligomer-mediated neurotoxicity *in vitro* as efficiently as the whole IgG molecule. The perceived advantages of using small Fab and scFv engineered antibody formats which lack the effector function include more efficient passage across the blood-brain barrier and minimizing the risk of triggering inflammatory side reactions. Furthermore, besides scFv and single-domain antibodies retain the binding specificity of full-length antibodies, they can be expressed as single genes and intracellularly in mammalian cells as intrabodies, with the potential for alteration of the folding, interactions, modifications, or subcellular localization of their targets; *see* for review, *e.g.*, Miller and Messer, Molecular Therapy 12 (2005), 394–401.

In a different approach Muller *et al.*, Expert Opin. Biol. Ther. (2005), 237-241, describe a technology platform, so-called 'SuperAntibody Technology', which is said to enable antibodies to be shuttled into living cells without harming them. Such cell-penetrating antibodies open new diagnostic and therapeutic windows. The term 'TransMabs' has been coined for these antibodies.

In a further embodiment, co-administration or sequential administration of other neuroprotective agents useful for treating a synucleinopathic disease may be desirable. In one

embodiment, the additional agent is comprised in the pharmaceutical composition of the present invention. Examples of neuroprotective agents which can be used to treat a subject include, but are not limited to, an acetylcholinesterase inhibitor, a glutamatergic receptor antagonist, kinase inhibitors, HDAC inhibitors, anti-inflammatory agents, divalproex sodium, or any combination thereof. Examples of other neuroprotective agents that may be used concomitant with pharmaceutical composition of the present invention are described in the art; see, *e.g.* international application WO2007/011907. In one embodiment, the additional agent is dopamine or a dopamine receptor agonist.

In a further embodiment of the present invention the α-synuclein binding molecules, in particular antibodies of the present invention may also be co-administered or administered before or after transplantation therapy with neural transplants or stem cell therapy useful for treating a synucleinopathic disease. Such approaches with transplants of embryonic mesencephalic neurons have been performed in patients with Parkinson's disease with the aim of replacing the neurons that are lost in the disease and reinstating dopaminergic neurotransmission in the striatum. After 11-16 years post transplantation, the grafted neurons were found to contain Lewy bodies and Lewy neurites. This spread of α-synuclein pathology from the host to the grated tissues may be prevented by co-administration of α-synuclein binding molecules, in particular antibodies of the present invention.

A therapeutically effective dose or amount refers to that amount of the active ingredient sufficient to ameliorate the symptoms or condition. Therapeutic efficacy and toxicity of such compounds can be determined by standard pharmaceutical procedures in cell cultures or experimental animals, *e.g.*, ED_{50} (the dose therapeutically effective in 50% of the population) and LD_{50} (the dose lethal to 50% of the population). The dose ratio between therapeutic and toxic effects is the therapeutic index, and it can be expressed as the ratio, LD_{50}/ED_{50}. Preferably, the therapeutic agent in the composition is present in an amount sufficient to restore or preserve normal behavior and/or cognitive properties in case of PD, DLB or other synucleinopathic diseases.

From the foregoing, it is evident that the present invention encompasses any use of an α-synuclein binding molecule comprising at least one CDR of the above described antibody, in particular for diagnosing and/or treatment of a synucleinopathic disease as mentioned above,

particularly Parkinson's disease. Preferably, said binding molecule is an antibody of the present invention or an immunoglobulin chain thereof. In addition, the present invention relates to anti-idiotypic antibodies of any one of the mentioned antibodies described hereinbefore. These are antibodies or other binding molecules which bind to the unique antigenic peptide sequence located on an antibody's variable region near the antigen-binding site and are useful, *e.g.*, for the detection of anti-α-synuclein antibodies in sample of a subject.

In another embodiment the present invention relates to a diagnostic composition comprising any one of the above described α-synuclein binding molecules, antibodies, antigen-binding fragments, polynucleotides, vectors or cells of the invention and optionally suitable means for detection such as reagents conventionally used in immuno or nucleic acid based diagnostic methods. The antibodies of the invention are, for example, suited for use in immunoassays in which they can be utilized in liquid phase or bound to a solid phase carrier. Examples of immunoassays which can utilize the antibody of the invention are competitive and non-competitive immunoassays in either a direct or indirect format. Examples of such immunoassays are the radioimmunoassay (RIA), the sandwich (immunometric assay), flow cytometry and the Western blot assay. The antigens and antibodies of the invention can be bound to many different carriers and used to isolate cells specifically bound thereto. Examples of well known carriers include glass, polystyrene, polyvinyl chloride, polypropylene, polyethylene, polycarbonate, dextran, nylon, amyloses, natural and modified celluloses, polyacrylamides, agaroses, and magnetite. The nature of the carrier can be either soluble or insoluble for the purposes of the invention. There are many different labels and methods of labeling known to those of ordinary skill in the art. Examples of the types of labels which can be used in the present invention include enzymes, radioisotopes, colloidal metals, fluorescent compounds, chemiluminescent compounds, and bioluminescent compounds; see also the embodiments discussed hereinabove.

By a further embodiment, the α-synuclein binding molecules, in particular antibodies of the present invention may also be used in a method for the diagnosis of a disorder in an individual by obtaining a body fluid sample from the tested individual which may be a blood sample, a lymph sample or any other body fluid sample and contacting the body fluid sample with an antibody of the instant invention under conditions enabling the formation of antibody-antigen complexes. The level of such complexes is then determined by methods known in the art, a

level significantly higher than that formed in a control sample indicating the disease in the tested individual. In the same manner, the specific antigen bound by the antibodies of the invention may also be used. Thus, the present invention relates to an *in vitro* immunoassay comprising the binding molecule, *e.g.*, antibody or antigen-binding fragment thereof of the invention.

In this context, the present invention also relates to means specifically designed for this purpose. For example, a antibody-based array may be used, which is for example loaded with antibodies or equivalent antigen-binding molecules of the present invention which specifically recognize α-synuclein. Design of microarray immunoassays is summarized in Kusnezow *et al.*, Mol. Cell Proteomics 5 (2006), 1681-1696. Accordingly, the present invention also relates to microarrays loaded with α-synuclein binding molecules identified in accordance with the present invention.

In one embodiment, the present invention relates to a method of diagnosing a synucleinopathic disease in a subject, the method comprising:

(a) assessing a level of α-synuclein in a sample from the subject to be diagnosed with an antibody of the present invention, an α-synuclein binding fragment thereof or an α-synuclein binding molecule having substantially the same binding specificities of any one thereof; and

(b) comparing the level of the α-synuclein to a reference standard that indicates the level of the α-synuclein in one or more control subjects,

wherein a difference or similarity between the level of the α-synuclein and the reference standard indicates that the subject has Parkinson's disease.

The subject to be diagnosed may be asymptomatic or preclinical for the disease. Preferably, the control subject has a synucleinopathic disease, for example PD, DLB or LBVAD, wherein a similarity between the level of α-synuclein and the reference standard indicates that the subject to be diagnosed has a synucleinopathic disease. Alternatively, or in addition as a second control the control subject does not have a synucleinopathic disease, wherein a difference between the level of α-synuclein and the reference standard indicates that the subject to be diagnosed has a synucleinopathic disease. Preferably, the subject to be diagnosed and the control subject(s) are age-matched. The sample to be analyzed may be any body fluid suspected to contain α-synuclein, for example a blood, CSF, or urine sample

The level of α-synuclein may be assessed by any suitable method known in the art comprising, *e.g.*, analyzing α-synuclein by one or more techniques chosen from Western blot, immunoprecipitation, enzyme-linked immunosorbent assay (ELISA), radioimmunoassay (RIA), fluorescent activated cell sorting (FACS), two-dimensional gel electrophoresis, mass spectroscopy (MS), matrix-assisted laser desorption/ionization-time of flight-MS (MALDI-TOF), surface-enhanced laser desorption ionization-time of flight (SELDI-TOF), high performance liquid chromatography (HPLC), fast protein liquid chromatography (FPLC), multidimensional liquid chromatography (LC) followed by tandem mass spectrometry (MS/MS), and laser densitometry. Preferably, said in vivo imaging of α-synuclein comprises positron emission tomography (PET), single photon emission tomography (SPECT), near infrared (NIR) optical imaging or magnetic resonance imaging (MRI).

Methods of diagnosing a synucleinopathic disease such as Parkinson's disease or Lewy body disease, monitoring a synucleinopathic disease progression, and monitoring a synucleinopathic disease treatment using antibodies and related means which may be adapted in accordance with the present invention are also described in international application WO2007/011907. Similarly, antibody based detection methods for α-synuclein are described in international applications WO99/50300, WO2005/047860, WO2007/021255 and WO2008/103472, the disclosure content of all being incorporated herein by reference. Those methods may be applied as described but with an α-synuclein specific antibody, binding fragment, derivative or variant of the present invention.

These and other embodiments are disclosed and encompassed by the description and examples of the present invention. Further literature concerning any one of the materials, methods, uses and compounds to be employed in accordance with the present invention may be retrieved from public libraries and databases, using for example electronic devices. For example the public database "Medline" may be utilized, which is hosted by the National Center for Biotechnology Information and/or the National Library of Medicine at the National Institutes of Health. Further databases and web addresses, such as those of the European Bioinformatics Institute (EBI), which is part of the European Molecular Biology Laboratory (EMBL) are known to the person skilled in the art and can also be obtained using internet search engines. An overview of patent information in biotechnology and a survey of relevant

sources of patent information useful for retrospective searching and for current awareness is given in Berks, TIBTECH 12 (1994), 352-364.

The above disclosure generally describes the present invention. Unless otherwise stated, a term as used herein is given the definition as provided in the Oxford Dictionary of Biochemistry and Molecular Biology, Oxford University Press, 1997, revised 2000 and reprinted 2003, ISBN 0 19 850673 2. Several documents are cited throughout the text of this specification. Full bibliographic citations may be found at the end of the specification immediately preceding the claims. The contents of all cited references (including literature references, issued patents, published patent applications as cited throughout this application and manufacturer's specifications, instructions, etc) are hereby expressly incorporated by reference; however, there is no admission that any document cited is indeed prior art as to the present invention.

A more complete understanding can be obtained by reference to the following specific examples which are provided herein for purposes of illustration only and are not intended to limit the scope of the invention.

EXAMPLES

The examples which follow further illustrate the invention, but should not be construed to limit the scope of the invention in any way. The following experiments in Examples 1 and 2 are illustrated and described with respect to antibody NI-202.3G12, NI-202.12F4, and NI-202.3D8 as cloned, *i.e.* containing primer induced mutations at the very N-termini of the framework 1 Ig-variable regions and not being adjusted to the germ line (GL) sequences of human variable heavy and light chains; see Figure 1. However, the other antibodies of the NI-202 series, in particular those with the adjusted GL sequences are structurally similar and thus may be expected to provide comparable results. These antibodies were expressed as human IgG1 molecules. The experiments in examples 3 and 4 are illustrated and described with respect to antibody NI-202.12F4 with primer induced mutations at the N-termini of the Ig-variable regions being adjusted to the germ line (GL) sequences of human variable heavy and light chains; see Figure 1. This antibody was expressed as a chimeric molecule where the adjusted human variable domains were fused to mouse IgG2a constant regions to allow for chronic dosing studies in transgenic mouse models without to induce a mouse anti-human immune response.

Material and methods

Detailed descriptions of conventional methods, such as those employed herein can be found in the cited literature. Unless indicated otherwise below, identification of α-synuclein-specific B cells and molecular cloning of α-synuclein antibodies displaying specificity of interest as well as their recombinant expression and functional characterization has been or can be performed as described in the Examples and Supplementary Methods section of international application PCT/EP2008/000053 published as WO2008/081008, the disclosure content of which is incorporated herein by reference in its entirety.

Purification of antigen

Recombinant His-α-synuclein was obtained by recombinant expression in Escherichia coli and subsequent purification using heat induced precipitation, Nickel affinity-, anion exchange- and size exclusion-chromatography.

For example, a DNA construct comprising the cDNA encoding α-synuclein under the control of the T7 promotor was used to transform an appropriate *Escherichia coli* strain such as BL21(DE3) and expression of 200 ml cell culture was induced by the addition of 1mM isopropyl β-D-thiogalactopyranoside (IPTG). Cells were harvested after 4 hrs induction at 37°C and then resuspended in 20 ml 50mM Tris, 150 mM NaCl pH 8, followed by sonification. After boiling for 15 min, the heat resistant 17000g supernatant was collected. Similar, heat-resistant 17000g supernatant from mock *Escherichia coli* was collected. After heat resistant 17000g supernatant (20 ml) from *Escherichia coli* expressing His-tagged α-synuclein was adjusted to 50 mM Tris, 300 mM NaCl, 20 mM Imidazole, pH 8, it was loaded onto a HisTrap HP 1ml (GE Life Science) column and HIS-α-synuclein was eluted with an 30-500mM imidazole gradient. Fractions containing HIS-α-synuclein were pooled and then diluted 1:10 with 50 mM Tris pH 8. Diluted pooled fractions were applied to a HiTrap Q HP 1ml (GE Life Science) column and bound proteins were eluted in a 30-1000 mM NaCl gradient. Finally, eluates containing HIS-α-synuclein were further purified using high performance gel filtration (Superdex 200 10/300 GL). This purification procedure yields HIS-α-synuclein with a purity grade of around 99% as estimated by SDS-PAGE and Coomassie staining. Concentration of purified protein has been determined using a BCA assay (Pierce).

α-synuclein antibody screening

96 well half area Microplates (Corning) were coated with purified HIS-α-synuclein or α-synuclein (rPeptide) at a standard concentration of 2μg/ml in coating buffer (PBS pH 9.6) overnight at 4°C. Plates were washed in PBS-T pH 7.6 and non-specific binding sites were blocked for 1 hr at RT with PBS-T containing 2% BSA (Sigma, Buchs, Switzerland). B cell conditioned medium was preabsorbed for 1 hr at RT with 10% Heat-resistant *E. coli* proteins in 1% BSA. This preabsorption step had been developed after several previous attempts of ELISA screening were unsuccessful in identifying human α-synuclein specific antibodies. Thus, fortunately it turned out that preabsorption of the ELISA plate with heat-resistant *E. coli* proteins excludes screening for false positive hits such as sticky antibodies and antibodies directed against *E. coli* protein contaminations probably present in purified recombinant α-synuclein samples. Preabsorbed medium was then transferred from memory B cell culture plates to ELISA plates and incubated for 2 hrs at RT. ELISA plates were washed in PBS-T and then incubated with horse radish peroxidase (HRP)-conjugated donkey anti-human IgG

(Fcγ fragment specific) polyclonal antibodies. After washing with PBS-T, binding of human antibodies was determined by measurement of HRP activity in a standard colorimetric assay.

Molecular cloning of α-synuclein antibodies

Samples containing memory B cells were obtained from volunteers >60 years of age. All volunteers had in common to lack any sign of Parkinsonism. Living B cells of selected memory B cell cultures are harvested and mRNA is prepared. Immunoglobulin heavy and light chain sequences are then obtained using Ig-framework 1 specific primers for all human variable heavy and light chain families as 5' primers in combination with primers specific for all human J segments (heavy and kappa light chain) and C segments (lambda light chain) as 3'primers (Marks *et al.*, Mol. Biol. 222 (1991), 581-597; de Haard *et al.*, J. Biol. Chem. 26 (1999), 18218-18230).

Identification of the antibody clone with the desired specificity is performed by re-screening on ELISA upon recombinant expression of complete antibodies. Recombinant expression of complete human IgG1 antibodies or chimeric IgG2a antibodies is achieved upon insertion of the variable heavy and light chain sequences "in the correct reading frame" into expression vectors that complement the variable region sequence with a sequence encoding a leader peptide at the 5'-end and at the 3'-end with a sequence encoding the appropriate constant domain(s). To that end the primers contained restriction sites designed to facilitate cloning of the variable heavy and light chain sequences into antibody expression vectors. Heavy chain immunoglobulin are expressed by inserting the immunoglobulin heavy chain RT-PCR product in frame into a heavy chain expression vector bearing a signal peptide and the constant domains of human immunoglobulin gamma 1 or mouse immunoglobulin gamma 2a. Kappa light chain immunoglobulin is expressed by inserting the kappa light chain RT-PCR-product of NI-202.3D8 in frame into a light chain expression vector providing a signal peptide and the constant domain of human kappa light chain immunoglobulin. NI-202.12F4 and NI-202.3G12 lambda light chain immunoglobulins are expressed by inserting the lambda light chain RT-PCR-product in frame into a lambda light chain expression vector providing a signal peptide and the constant domain of human or mouse lambda light chain immunoglobulin.

Functional recombinant monoclonal antibodies are obtained upon co-transfection into HEK293 or CHO cells (or any other appropriate recipient cell line of human or mouse origin) of an Ig- heavy–chain expression vector and a kappa or lambda Ig-light–chain expression vector. Recombinant human monoclonal antibody is subsequently purified from the conditioned medium using a standard Protein A column purification. Recombinant human monoclonal antibody can produced in unlimited quantities using either transiently or stably transfected cells. Cell lined producing recombinant human monoclonal antibody can be established either by using the Ig-expression vectors directly or by re-cloning of Ig-variable regions into different expression vectors. Derivatives such as F(ab), $F(ab)_2$ and scFv can also be generated from these Ig-variable regions.

Antibodies

Rabbit polyclonal pan synuclein antibody (Abcam), mouse monoclonal LB509 α-synuclein specific antibody (Invitrogen), antibody Syn211 (Sigma) and Clone 42 (BD Biosciences) were used according to manufacturer's protocol. Recombinant human α-synuclein antibodies NI202.3G12, NI202.12F4 and NI-202.3D8 are antibodies of this invention. They were expressed in HEK293 or CHO cells and then conditioned media was directly used in subsequent applications unless otherwise stated. In Examples 3 to 5 purified recombinant antibodies of the present invention were used.

Direct ELISA

Antigens were coated at indicated concentration in PBS pH 9.6 onto 96 well half area microplates (Corning) overnight at 4°C. Plates were washed in PBS-T pH 7.6 and non-specific binding sites were blocked for 1 hr at RT with PBS-T containing 2% BSA (Sigma). Probes (Primary antibodies) were then transferred to wells and incubated for 2 hrs at RT. After washing in PBS-T pH 7.6, wells were incubated with horse radish peroxidase (HRP)-conjugated polyclonal anti-human (for recombinant human antibodies), anti-rabbit (for pan synuclein antibody) or anti-mouse (for LB509 or Syn211) secondary antibodies for 1 hr at RT. After rigorous washing in PBS-T, binding of probes was determined by measurement of HRP activity in a standard colorimetric assay using 3,3',5,5'-tetramethylbiphenyl-4,4'-diamine (Sigma) as chromogenic substrate.

Western Blotting and Coomassie protein staining

To assess binding to human and mouse α-synuclein, frozen brains of wild type or α-synuclein transgenic mice were homogenized in PBS (10 ml/g wet weight) using a Dounce homogenizer. The extract was spun at 100'000 g and the supernatant was designated soluble fraction. Soluble fraction or recombinant proteins (750 ng) were mixed with loading dye, heated at 65°C for 10 min and 0.75 µg was loaded per lane and separated on a 4-20% Tris-Glycine SDS-PAGE. Gels were either stained in 0.025% Coomassie Brilliant blue R 250 (Fluka) solution or electroblotted to nitrocellulose transfer membrane. Blots were then incubated with primary antibody for 2 hrs. Binding of primary antibodies was revealed using secondary anti human antibodies conjugated with HRP. Blots were developed using ECL plus Western Blotting Detection Reagents (GE Healthcare).

To assess binding to α-synuclein monomers and aggregates, brain extracts were prepared in PBS containing 0.5% Triton X100 followed by centrifugation at 1000 g for 5 min. Supernatants were separated by 4-12% Bis-Tris NuPAGE gel electrophoresis and analyzed by WB.

Pole Test

Mice are tested at the beginning of the dark phase when they are most active. The pole is made of a wooden stick with 50 cm length and 1 cm width covered with cloth to facilitate climbing. The base of the pole is placed in the home cage of the mouse. The mouse is placed on the top of the pole and the time to orient downwards and time to climb down to the home cage is recorded over 5 trials with 30 min intertrial intervals. The best performance trial is analyzed.

Elevated plus maze test

Mice are tested at the beginning of the dark phase when they are most active. Testing is performed in dim light (40 lux). The elevated plus maze consists of two open and two closed arms (arm length: 30 cm; width: 5 cm). Open arms have a small 1 cm edge and the closed arms are bordered by a 15 cm wall. At the beginning of the task, mice are placed in the center of the elevated plus maze facing an open arm. Mice are video-tracked while exploring the maze for 5 min. The time spent in the open and closed arms and the distance covered are measured and analyzed.

Transgenic mice

B6;C3-Tg(Prnp-SNCA*A53T)83Vle/J (Giasson *et al.*, Neuron. 34 (2002), 521-533) transgenic α-synuclein mice and corresponding wild type mice were kept under standard housing conditions on a reversed 12h:12h light/dark cycle with free access to food and water. The treatment groups were balanced for age and gender.

Determination of NI-202.12F4 and α-synuclein levels in mouse plasma

NI-202.12F4 plasma levels were determined using a direct α-synuclein ELISA using recombinant NI-202.12F4 of known concentration as standard. For determination of human α-synuclein levels in plasma a sandwich ELISA was applied (Invitrogen, USA).

Example 1: Identification of human α-synuclein-specific antibodies with different epitope specificities

α-synuclein is a 140 amino acids (aa) long natively unfolded protein that is composed of three domains. These are the N-terminal amphipathic repeat region (1-60 aa), the center region (61-95 aa) and the acidic C-terminal region (96-140). To further understand the specificity of recombinant human α-synuclein antibodies, the domain of α-synuclein that contains the recognition sequence was determined. α-synuclein truncations 1-60 aa, 1-95 aa, 61-140 aa and 96-140 aa were coated at equal concentration onto ELISA plates and recombinant human α-synuclein autoantibodies NI-202.3G12 and NI-202.12F4 were then probed for binding to these truncations.

Interestingly, NI-202.3G12 does only bind to coated full length α-synuclein but not to any of the four tested truncations (Fig. 2A). This suggests that the recognition epitope of NI-202.3G12 is a structural motif rather than a linear primary recognition sequence.

On the other hand NI-202.12F4 binds to α-synuclein fragments comprising aa 1-60 (Fig. 2B) but not to N-terminally truncated fragments comprising amino acids 61-140 or 96-140. This shows that its epitope is localized within the N-terminus. Notably, characterization of mouse monoclonal antibodies which selectively bind α-synuclein in pathological inclusions, revealed that their epitopes are within the very N-terminal segment (Waxman *et al.*, Acta Neuropathol. 116 (2008), 37-46.

In addition, preliminary results of direct ELISA assays performed with antibody NI-202.3D8 revealed that NI-202.3D8 specifically recognizes the C-terminus of α-synuclein, in particular amino acids 96-140. Deletion of key amino acids 125–140 within the C-terminal domain greatly alters α-synuclein aggregation and in the brains of patients with Dementia with Lewy body disease (LBD) as well as in transgenic animal models, there is abundant accumulation of C-terminal α-synuclein fragments. These studies suggest that antibodies capable of recognizing the C-terminal region might have potential therapeutic effects; see Masliah *et al.*, Neuron, 46 (2005), 857–868.

To exclude that C-terminal α-synuclein comprising truncations are not efficiently coated onto ELISA plates, epitope mapping of the mouse monoclonal alpha synuclein antibody LB509

(Baba *et al.*, Am. J. Pathol. 152 (1998), 879–884) was performed. LB509 binds to a C-terminal epitope (Jakes *et al.*, Neuroscience Letters 269 (1999), 13-16). As shown in Fig. 2C, this study confirms the C-terminal epitope of LB509 and thus confirms efficient coating of C-terminal α-synuclein fragments. In conclusion, epitope mapping of recombinant human α-synuclein antibodies in the experiments performed in accordance with the present invention shows that these antibodies are directed against different epitopes including conformational epitopes and potential pathological structures in the N-terminus and the C-terminus.

Example 2: The human antibodies are specific for α-synuclein

α-, β- and γ-synuclein are highly homologues proteins that are predominantly expressed in the nervous system, skeletal muscle and heart. However, only abnormal α-synuclein is linked to a broad spectrum of CNS diseases while β-synuclein is suggested to be an inhibitor of α-synuclein aggregation and may protect the central nervous system from the neurotoxic effects of α-synuclein. Thus (therapeutic) antibodies against pathological α-synuclein variants preferentially do not cross react with β- and γ-synuclein. In order to support specificity and potential therapeutic use of recombinant human anti-α-synuclein antibodies, the candidate antibodies were probed for α-, β- and γ-synuclein binding in a direct ELISA assay and by Western blotting (WB). First, recombinant α-, β- and γ-synuclein have been coated onto ELISA plates at equal coating concentration (2µg/ml) and were then either incubated with a pan synuclein control antibody or recombinant human α-synuclein antibodies. The pan synuclein antibody reacts with all three synuclein proteins coated on ELISA plates (Fig 3A). Then recombinant human α-synuclein antibodies were probed for specific α-synuclein binding. Both NI-202.3G12 and NI-202.12F4 react with coated α-synuclein but not β- and γ-synuclein (Figs. 3A and 3B).

Similar, the specificity of the recombinant antibodies was also investigated using WB analysis. Coomassie protein staining confirms that equal concentrations of all three synuclein proteins have been applied to SDS PAGE analysis (Fig 4A). WB analysis then shows that NI-202.12F4 selectively binds to α-synuclein (Fig. 4B) whereas without primary antibody no signal was detected (Fig. 4C). NI-202.3G12 binding to α-synuclein on WB was undetectable. This is in agreement with a structural epitope rather than a linear recognition sequence of NI-202.3G12. These findings demonstrate that recombinant human alpha synuclein antibodies described in the present invention can be highly specific.

All subsequent experiments were performed with the NI-202.12F4 mouse chimeric antibody.

Example 3: Binding specificities of antibody NI-202.12F4

Specific binding to human α-synuclein with a preference for aggregated α-synuclein species

To assess the binding of NI-202.12F4 to human and mouse α-synuclein, brain extracts were prepared from wild type and α-synuclein A53T transgenic mice and antibody binding was analyzed by Western blotting. NI-202.12F4 detects a prominent band corresponding to α-synuclein in brain extracts from human A53T α-synuclein transgenic mice while such band is virtually absent in brain extracts from wild type mice (Figure 5 A), suggesting specific binding to human but not mouse α-synuclein. Similar results were obtained with the commercially available LB509 antibody (Jakes *et al.*, Neuroscience Letters 269 (1999), 13-16) directed against an epitope specific for human α-synuclein. In contrast, the commercially available antibody clone 42 (van der Putten *et al.*, J. Neurosci. 20 (2000), 6021-6029) which was reported to bind α-synuclein of both species, detected human as well as mouse α-synuclein protein. These data suggest that NI-202.12F4 preferentially binds to human α-synuclein.

To assess the binding of NI-202.12F4 to physiological forms as well as pathological aggregates of human α-synuclein, cortical brain extracts from a healthy control subject and a dementia with Lewy bodies (DLB) patient as well as extracts from wild type mice and human A30P α-synuclein transgenic mice brain (Kahle *et al.* J. Neurosci. 20 (2000), 6365-73) were prepared, separated by SDS gel electrophoresis and analyzed by Western blotting. NI-202.12F4 detects with high sensitivity a prominent smear reflecting oligomeric and fibrillar forms of α-synuclein aggregates in DLB and A30P α-synuclein transgenic brain extract but not in healthy control and wild type control extracts (Figure 5 B). In contrast minimal binding was observed to monomeric forms of α-synuclein in human or wild type mouse tissues and moderate binding in A30P α-synuclein transgenic brain extracts highly overexpressing the α-synuclein protein. In contrast, clone 42 antibody showed the opposite binding pattern in the Western blot analysis, detecting monomeric forms and α-synuclein fragments with a high sensitivity and poorly binding to aggregated α-synuclein species. These results suggest that NI-202.12F4 preferentially binds to pathological aggregates of α-synuclein such as oligomers and fibrils over physiological α-synuclein monomers.

NI-202.12F4 binds to wild type and disease causing mutants of human alpha synuclein with high affinity

The half maximal effective concentration (EC50) was determined for wild type as well as disease causing human α-synuclein mutants using a direct α-synuclein ELISA. High affinity binding was observed for the wild type as well as the A30P, E46K and A53T mutant forms of human α-synuclein (Figure 6).

Recombinant NI-202.12F4 preferentially binds to pathological forms of α-synuclein in brain.

Binding of NI-202.12F4 to α-synuclein was further characterized by immunohistochemical staining of brain sections from α-synuclein transgenic mice and patients with neuropathologically confirmed Parkinson's Disease or dementia with Lewy bodies. NI-202.12F4 shows prominent staining of α-synuclein pathology including Lewy body and Lewy neurite like inclusion as well as small somatodendritic and synaptic accumulations of α-synuclein in free-floating sections from transgenic mice expressing either human A53T (Figure 7 A) or A30P α-synuclein (Figure 7 B) as well as in human brain tissues of Parkinson's disease and dementia with Lewy bodies (Figure 7 C, D). In contrast to the commercially available Syn211 antibody (Giasson *et al.*, J. Neurosci. Res. 59 (2000), 528-33) which detects also physiological synaptic α-synuclein with a high sensitivity (Figure 7 E), NI-202.12F4 binds preferentially to pathological aggregates of α-synuclein as exemplified by immunohistochemical staining of human A30P α-synuclein transgenic mice (Figure 7 B). Binding of NI-202.12F4 is virtually absent on brain sections of wild type mice (Figure 7 F) comparable to secondary antibody only control staining (Figure 7G) confirming the preferential binding to human versus mouse α-synuclein as was observed in the Western blot analysis (Figure 5). In contrast, the commercially available clone 42 antibody (van der Putten *et al.*, J. Neurosci. 20 (2000), 6021-6029) which was reported to bind α-synuclein of human as well as mouse origin, showed prominent synaptic staining of mouse α-synuclein protein in brain sections of wild type mice (Figure 7 H).

NI-202.12F4 shows preferential binding to human α-synuclein at high coating concentrations pointing to a conformational epitope

The half maximal effective concentration (EC50) indicating the potency of an antibody was determined for low and high coating concentrations of recombinant α-synuclein using a direct α-synuclein ELISA. High affinity binding of recombinant NI-202.12F4 with an EC50 of ~100

pM was observed for high coating densities of α-synuclein protein (20 µg/ml). At lower coating concentrations of α-synuclein, a sharp drop in affinity was observed, with a corresponding increase in EC50 by close to 100-fold (Figure 8 A). In contrast, the commercially available Syn211 antibody (Giasson *et al.*, J. Neurosci. Res. 59 (2000), 528-33) directed against a linear epitope within the α-synuclein C-terminus showed no decrease in binding affinity at lower coating densities of alpha synuclein (Figure 8 B). These findings suggest that NI-202.12F4 preferentially targets a structural epitope of α-synuclein that is formed at high concentrations of α-synuclein. The results are consistent with the immunohistochemical binding characteristics of NI-202.12F4 that suggest a preference for pathologic conformations of α-synuclein aggregates such as α-synuclein fibrils or oligomers. As was observed for full-length α-synuclein, NI-202.12F4 binding to truncated α-synuclein 1-60 shows equivalent dependence on the coating concentration pointing to a conformational epitope that is contained within amino acids 1-60 of the α-synuclein protein (Figure 8 C). It can however not be excluded that amino acids 60-140 of α-synuclein can influence the formation of the N-terminal epitope. Notably, the N-terminal amino acids 1-60 of human α-synuclein containing the A53T mutation are 100% identical to the N-terminus of mouse α-synuclein. Thus the observed preference for human α-synuclein versus the mouse ortholog could be due to an influence of the C-terminal part of synuclein on the accessibility or formation of the preferred NI-202.12F4 epitope at the N-terminus. Epitope mapping studies using smaller N-terminal derived fragments of α-synuclein (amino acids 1-20; 21-40; 41-60; 11-30; 31-50) revealed no binding of the NI-202.12F4 antibody to any of the peptides, suggesting that these regions are not sufficient for binding of NI-202.12F4 (Figure 8 D).

Example 4: Recombinant human-derived antibody against alpha-synuclein improves motor performance and elevated plus maze behavior in a transgenic mouse model of Parkinson's disease

To assess the pharmacological effects of NI-202.12F4 treatment, 10.5 months old transgenic mice overexpressing the human A53T α-synuclein transgene (Giasson *et al.*, Neuron 34 (2002), 521-533) were treated weekly i.p. with 5 mg/kg of recombinant chimeric NI-202.12F4 antibody or vehicle control for a total of 4 months. After 2 months of treatment, motor performance was evaluated in the pole test. NI-202.12F4 treated mice showed a significant improvement in motor performance compared to the vehicle treated group with significantly reduced time to turn on the pole (Ttum; $p<0.001$; n=17-19 animals per group) as well as total

time to descend into the home cage (Ttotal; $p<0.05$; n=17-19 animals per group) as is shown in Figure 9. In a second behavior test the treatment effects on elevated plus maze performance was analyzed. α-synuclein A53T transgenic mice were previously reported to exhibit impaired elevated plus maze behavior, spending more time in open arms compared to wild type controls (George *et al.*, Exp. Neurol., 210 (2008), 788-92). As shown in Figure 10 chronic treatment with NI-202.12F4 lead to a significant improvement in elevated plus maze behavior in α-synuclein A53T transgenic animals. Antibody treated mice spend significantly less time and covered a significantly lower distance in open arms compared to vehicle treated animals ($p<0.05$; n=17-19 animals per group) while the activity levels were equivalent for both groups. These results demonstrate that chronic treatment with the NI-202.12F4 antibody leads to significant improvements in motor performance and rescues abnormal elevated plus maze behavior in α-synuclein transgenic mouse models of Parkinson's disease.

Example 5: NI-202.12F4 antibody increases plasma synuclein levels in synuclein transgenic mouse models of Parkinson's disease

10.5 old month transgenic A53T α-synuclein transgenic mice were treated weekly i.p. for 2 month with 5 mg/kg chimeric NI-202.12F4 or PBS. 24h after the last injection, plasma samples were prepared and the plasma concentrations of treatment antibody and human α-synuclein were determined by ELISA (Figure 11). Plasma levels of human α-synuclein were significantly increased by more than 10 fold compared to vehicle treated animals (25 ± 4.1 ng/ml for NI-202.12F4 treatment group vs. 1.9±1.2 ng/ml for PBS group, $p = 0.0002$) demonstrating pharmacodynamic modulation of α-synuclein upon treatment with NI-202.12F4. Similar effects were observed upon acute antibody treatment in the A30P α-synuclein transgenic mice. As in the A53T and A30P α-synuclein transgenic models human α-synuclein is predominantly expressed in the brain, the increase in circulating human α-synuclein could be due to a NI-202.12F4 mediated net efflux of α-synuclein from brain to the periphery.

CLAIMS

1. An anti-α-synuclein antibody, or an α-synuclein binding fragment thereof, wherein the antibody or α-synuclein binding fragment thereof comprises a heavy chain variable region (VH) comprising:

a VH CDR1 comprising residues 31-35 of SEQ ID NO:9,

a VH CDR2 comprising residues 50-68 of SEQ ID NO:9, and

a VH CDR3 comprising residues 101-102 of SEQ ID NO:9,

and a light chain variable region (VL) comprising:

a VL CDR1 comprising residues 23-33 of SEQ ID NO:12,

a VL CDR2 comprising residues 49-55 of SEQ ID NO:12, and

a VL CDR3 comprising residues 88-98 of SEQ ID NO:12.

2. An anti-α-synuclein antibody, or an α-synuclein binding fragment thereof, comprising:

a) a VH region comprising the amino acid sequence of SEQ ID NO:10 and

b) a VL region comprising the amino acid sequence of SEQ ID NO:13.

3. An anti-α-synuclein antibody, or an α-synuclein binding fragment thereof, comprising:

a) a VH region comprising the amino acid sequence of SEQ ID NO:9 and

b) a VL region comprising the amino acid sequence of SEQ ID NO:12.

4. The anti-α-synuclein antibody or α-synuclein binding fragment thereof of any one of claims 1-3, which is

(i) detectably labeled, wherein the detectable label is selected from the group consisting of an enzyme, a radioisotope, a fluorophore and a heavy metal; or

(ii) attached to a drug.

5. The anti-α-synuclein antibody or α-synuclein binding fragment thereof of any one of claims 1-3 comprising a human IgG 1 heavy chain constant region.

6. The anti-α-synuclein antibody or α-synuclein binding fragment thereof of any one of claims 1-5 comprising a human lambda light chain constant region.

7. A composition comprising the anti-α-synuclein antibody or α-synuclein binding fragment thereof of any one of claims 1-6 wherein the composition is

(i) a pharmaceutical composition further comprising a pharmaceutically acceptable carrier; or

(ii) a diagnostic composition further comprising one or more immuno or nucleic acid based diagnostic reagents.

8. A kit for the diagnosis of a synucleinopathic disease, said kit comprising the anti-α-synuclein antibody or α-synuclein binding fragment thereof of any one of claims 1-6 with reagents and/or instructions for use.

9. The kit of claim 8, wherein the synucleinopathic disease is Parkinson's disease.

10. An isolated polynucleotide or polynucleotides encoding the anti-α-synuclein antibody or α-synuclein binding fragment thereof of any one of claims 1-6.

11. An expression vector or vectors comprising the polynucleotide or polynucleotides of claim 10.

12. A host cell comprising the expression vector or vectors of claim 11.

13. A method for preparing an anti-α-synuclein antibody or an α-synuclein binding fragment thereof, said method comprising:

(a) culturing the cell of claim 12; and

(b) isolating said antibody or fragment thereof from the culture.

14. The use of the anti-α-synuclein antibody or α-synuclein binding fragment thereof of any one of claims 1-6 in the manufacture of a medicament for treatment of a synucleinopathic disease in a human subject.

15. The use of claim 14, wherein the synucleinopathic disease is selected from the group consisting of Parkinson's disease (PD), Parkinson's disease dementia (PDD), dementia with Lewy bodies (DLB), the Lewy body variant of Alzheimer's disease (LBV AD), multiple systems atrophy (MSA), pure autonomic failure (PAF), neurodegeneration with brain iron accumulation type-I (NBIA-1), Alzheimer's disease, Pick's disease, juvenile-onset generalized neuroaxonal dystrophy (Hallervorden-Spatz disease), amyotrophic lateral sclerosis, traumatic brain injury, and Down’s syndrome.

16. The use of claim 14, wherein the synucleinopathic disease is Parkinson’s disease.

17. A method of diagnosing a synucleinopathic disease in a human subject, the method comprising:

(a) assessing a level of α-synuclein in a sample from the human subject to be diagnosed with the anti-α-synuclein antibody or α-synuclein binding fragment thereof of any one of claims 1-6; and

(b) comparing the level of the α-synuclein to a control, wherein a difference or similarity between the level of the α-synuclein and the control indicates that the human subject has a synucleinopathic disease.

18. The method of claim 17, wherein the synucleinopathic disease is selected from the group consisting of Parkinson's disease (PD), Parkinson's disease dementia (PDD), dementia with Lewy bodies (DLB), the Lewy body variant of Alzheimer's disease (LBV AD), multiple systems atrophy (MSA), pure autonomic failure (PAF), neurodegeneration with brain iron accumulation type-I (NBIA-1), Alzheimer's disease, Pick's disease, juvenile-onset generalized neuroaxonal dystrophy (Hallervorden-Spatz disease), amyotrophic lateral sclerosis, traumatic brain injury, and Down’s syndrome.

19. The method of claim 17, wherein the synucleinopathic disease is Parkinson's disease.

20. The use of the anti-α-synuclein antibody or α-synuclein binding fragment thereof of any one of claims 1-6 attached to a therapeutic or diagnostic agent in the manufacture of a medicament for *in vivo* detection of or targeting a therapeutic and/or diagnostic agent to α-synuclein in a human subject, wherein the α-synuclein is to be detected by positron emission tomography (PET), single photon emission tomography 20 (SPECT), near infrared (NIR) optical imaging, magnetic resonance imaging (MRI), or a combination thereof.

21. The anti-α-synuclein antibody or α-synuclein binding fragment thereof of any one of claims 1-6 for use as a medicament.