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Ficht et al.

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(54) **HSP20 INHIBITS AMYLOIDOGENESIS AND NEUROTOXICITY**

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(51) **Int. Cl.**

A61K 38/17 (2006.01)
A61K 39/00 (2006.01)
A61K 39/002 (2006.01)
C07K 14/44 (2006.01)

(52) **U.S. Cl.**

USPC **514/17.8**; 514/17.7; 514/12.2; 514/21.2;
530/350; 424/191.1; 424/192.1

(58) **Field of Classification Search**

None

See application file for complete search history.

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Primary Examiner — Jeffrey Stucker

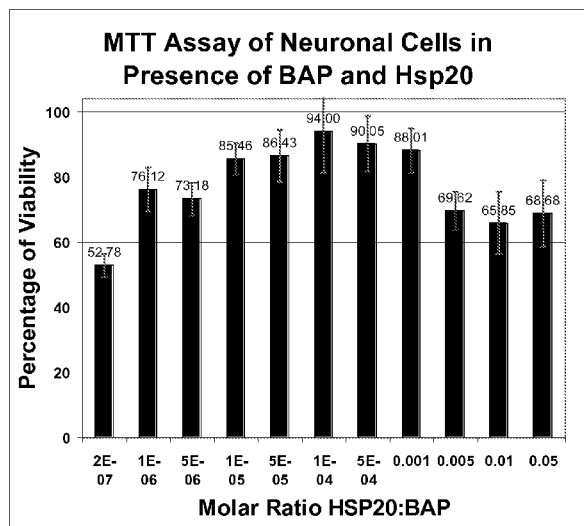
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(57) **ABSTRACT**

The present invention compositions and methods of using at least a portions of an isolated and purified α -crystallin polypeptide that includes one or more β -pleated sheets and that prevents neurotoxicity and amyloidogenesis.

9 Claims, 15 Drawing Sheets



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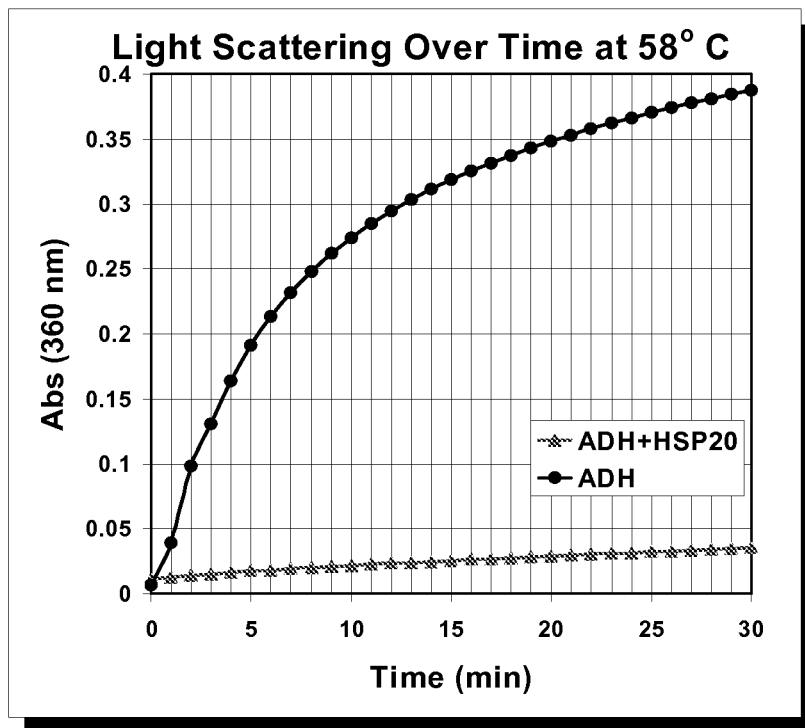


Figure 1

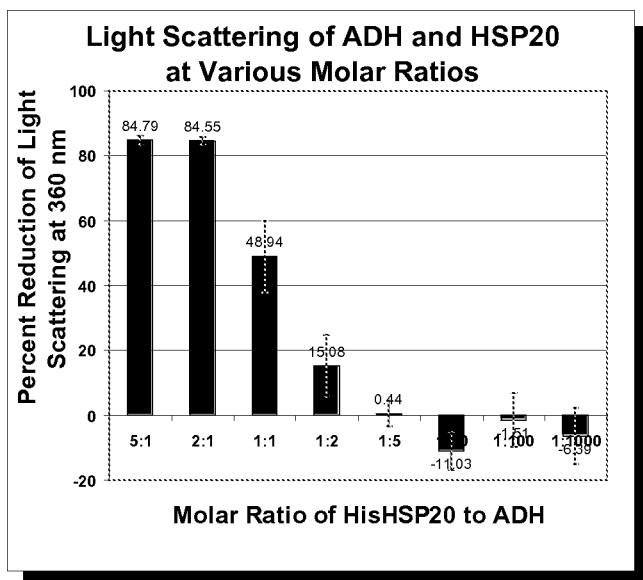


Figure 2

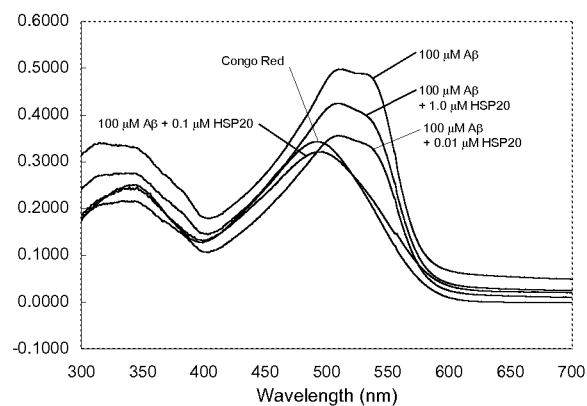


Figure 3

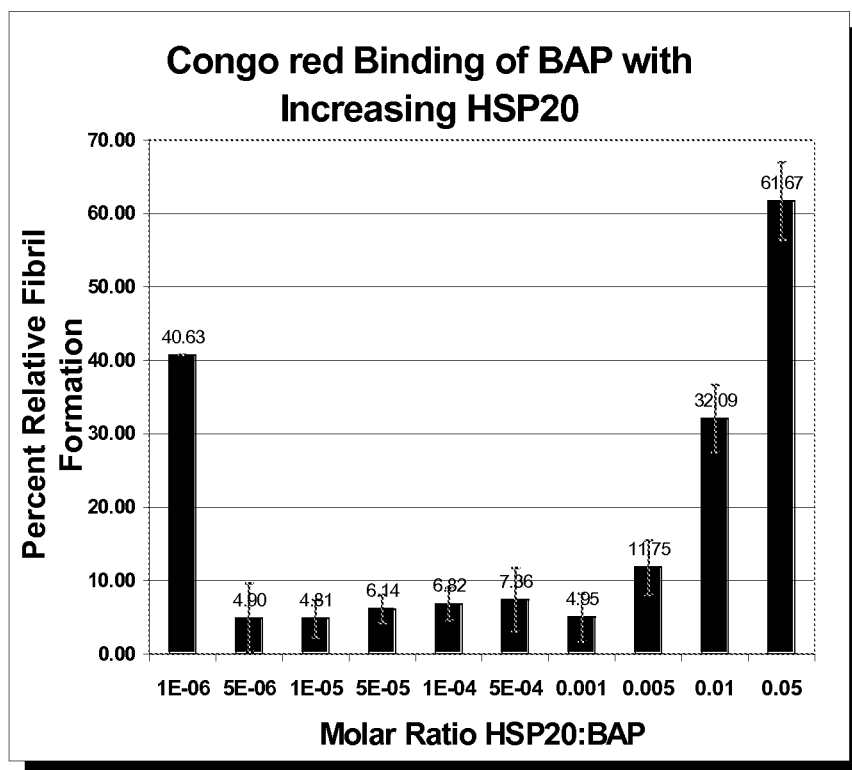


Figure 4

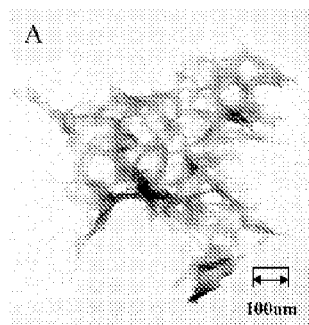


Figure 5A

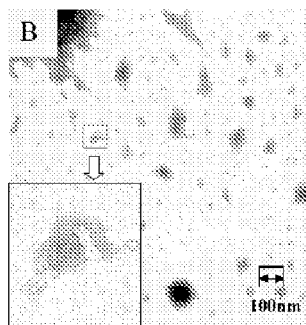


Figure 5B

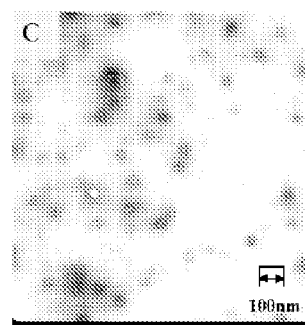


Figure 5C

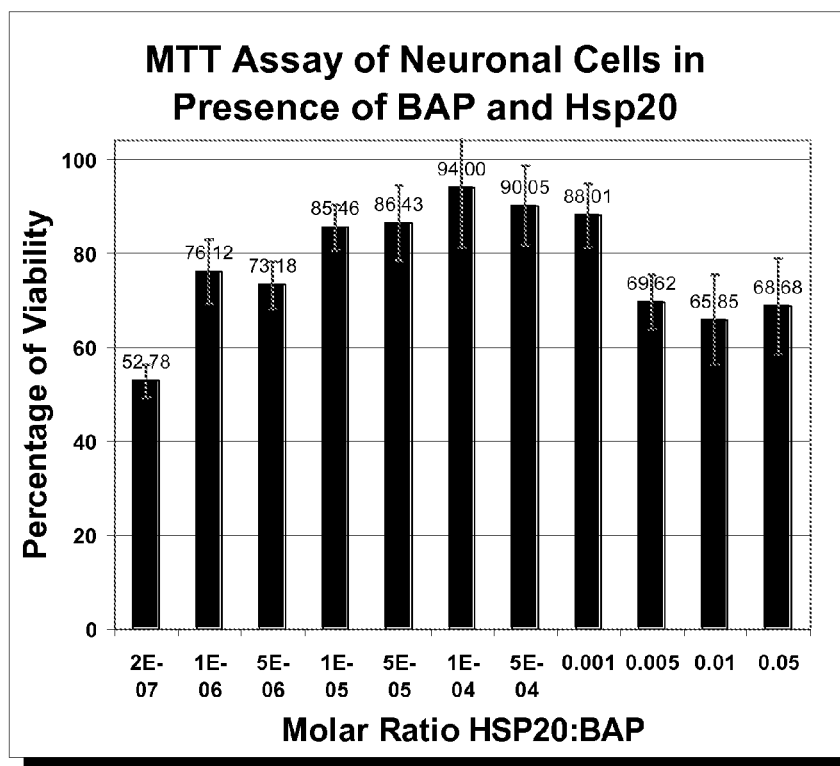


Figure 6

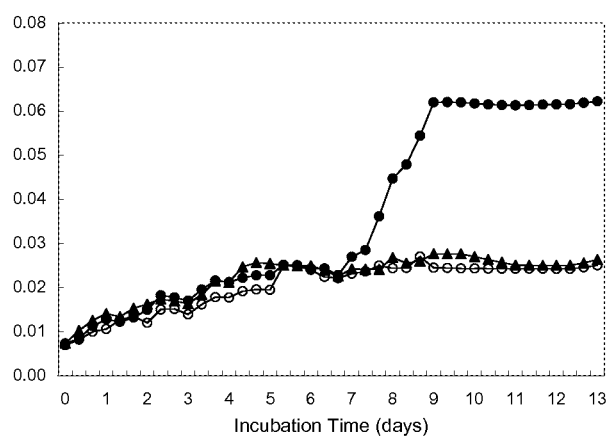


Figure 7

ATGGGGGGTTCTCATCATCATCATCATGGTATGGCTAGCATGACTGGTGGAC
AGCAAATGGGTCTGGGATCTGTACGACGATGACGATAAGGATCCAACCCTTGAAA
ATCTTTATTTTCAAGGTATGTCGTGCATTATGAGGTGCAACAACCTCCGAACAGGA
GGTTGTCATCGATGAGCAGACGGGACTCCCAGTGAAGAACCACGACTACACTGA
GAAGCCCTCTGTGATTTACAAGCCGTCGACCATTGTTCCCTCAAAACACCATCCTT
GAGATCCCTCCTCCCAAGGAACTGGAAACCCCTATCACCTTCAACCCCAACCGTC
GACACCTTTTTCGATGCTGACACCAACAAGATCGTTGTTTTGATGGAAGTGCCTG
GATTCAGCCACAACGACATCACTGTGGAGTGC GGTTTGGGAGAACTCATCATCA
GCGGCCCCCGCCCCAAGGACGAGCTTTACGAGAAGTTCGGTAACAACCTTGACA
TCCACATCCGTGAGCGCAAGGTTGGTTACTTCTACAGGCGCTTCAAGCTCCCGC
ACAACGCCTTGGACAAGTCTGTTGCTGTGTCTTACTCCAACGGTATCTTGGACAT
CAGGATTGAGTGCTCGCAGTTCTCCGAGATGCGCCGCATCCAGATCGACGGCAA
GGCATAA

Figure 8

MGGSHHHHHHGMASMTGGQQMGRDLYDDDDKDPTLENLYFQGMSCIMRCNNSE
QEVVIDEQTGLPVKNHDYTEKPSVIYKPSTIVPQNTILEIPPPKELETPITFNPTVDTFF
DADTNKIVVLMELPGFSHNDITVECGLGELIISGPRPKDELYEKFNNLDIHIRERKVG
YFYRRFKLPHNALDKSVAVSYSNGILDIRIECSQFSEMRRIQIDGKA

Figure 9

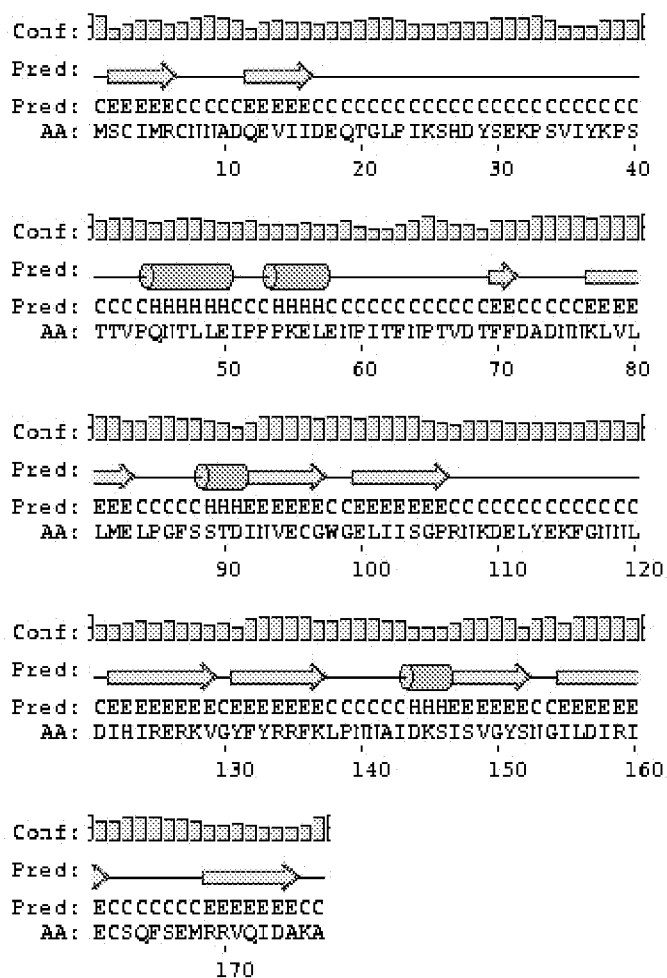


Figure 10

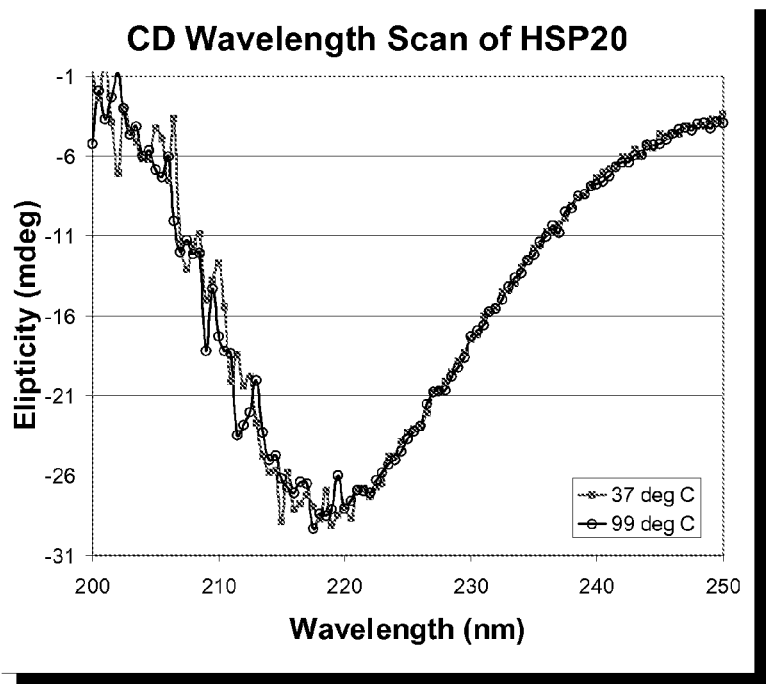
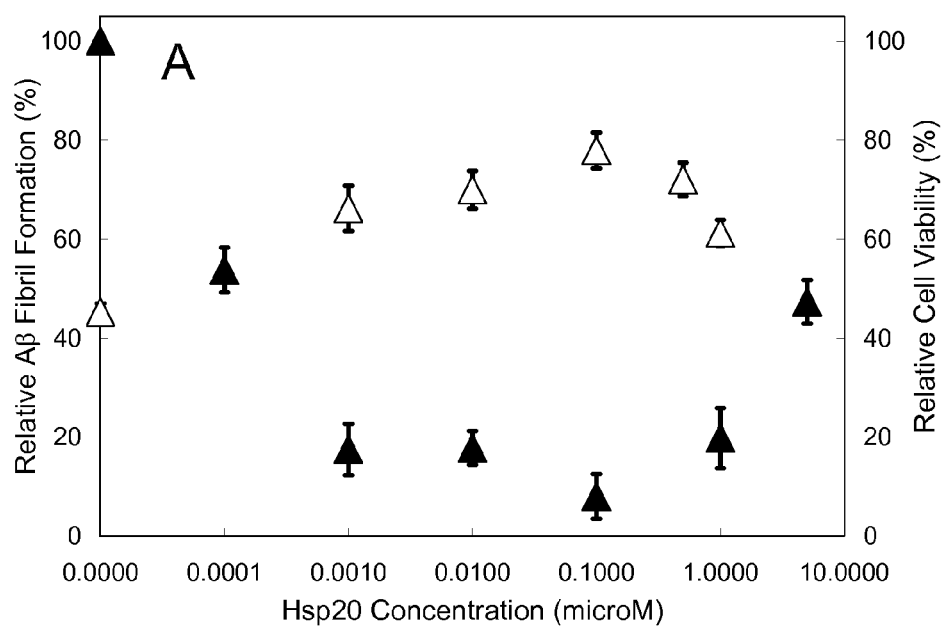


Figure 11

Figure 12A β

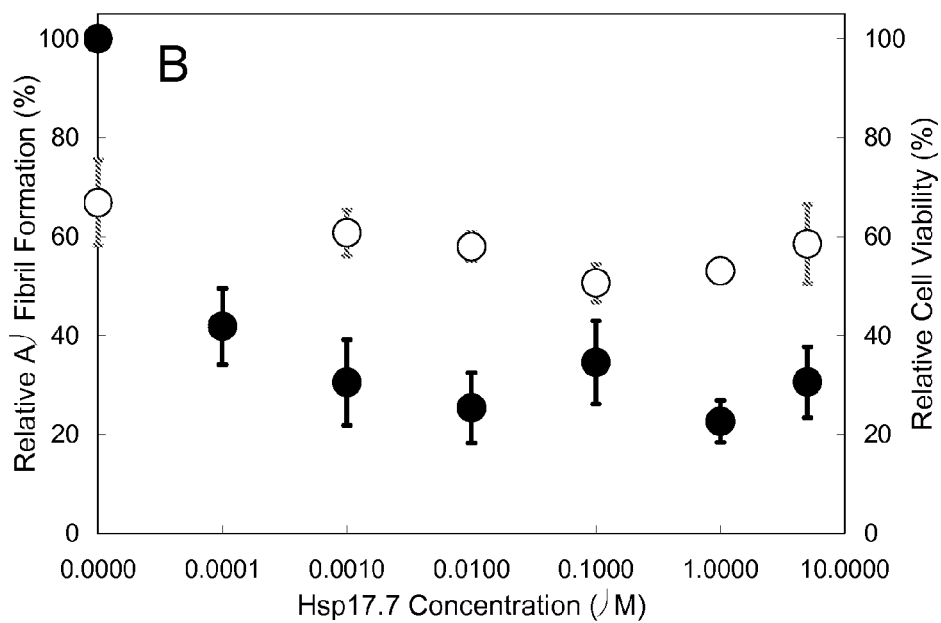


Figure 12B

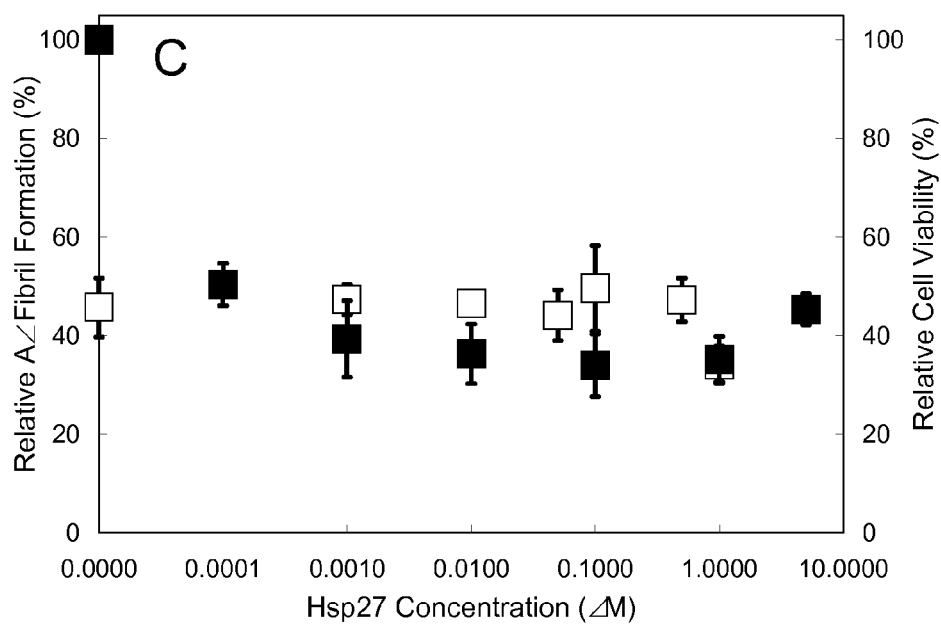


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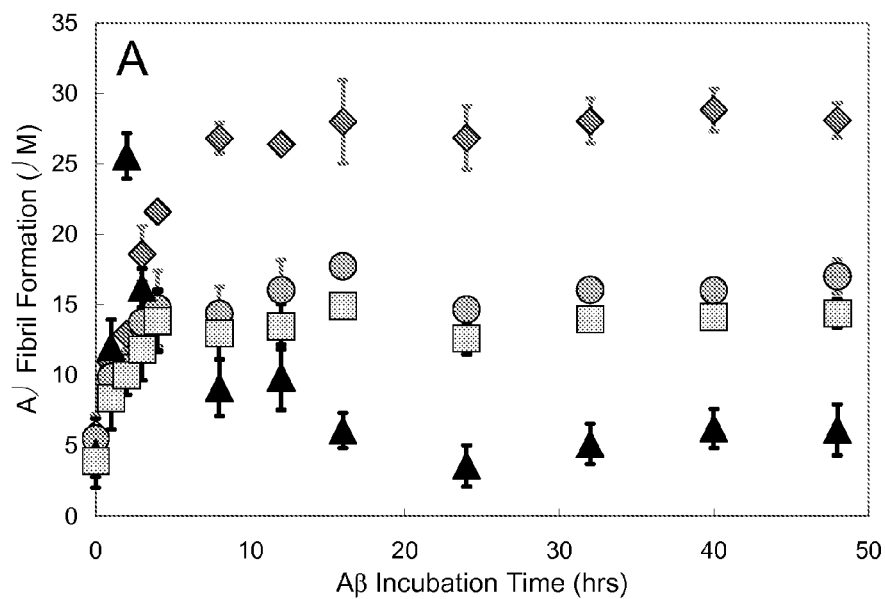


FIGURE 13

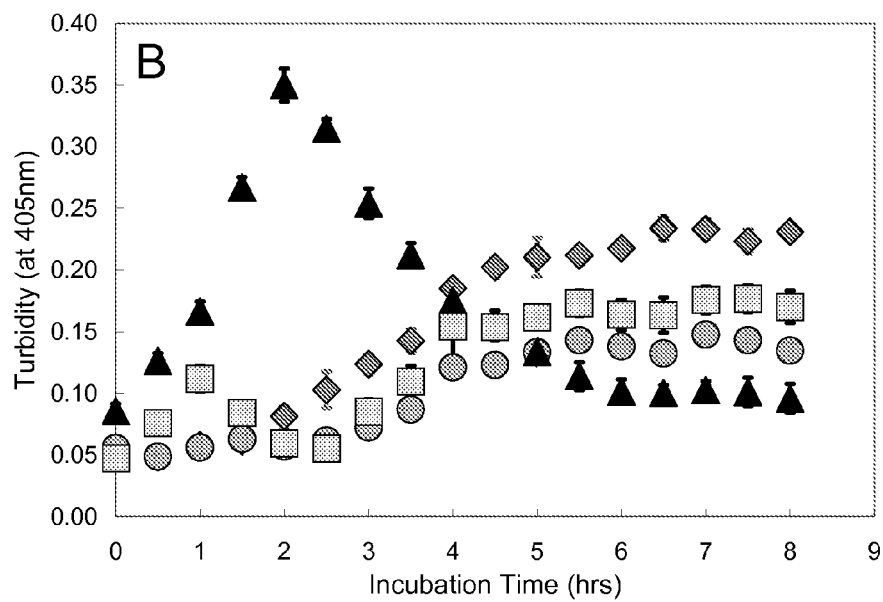


FIGURE 14

FIGURE 15

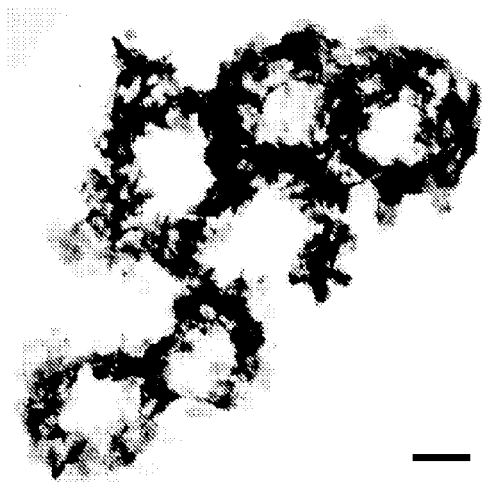


FIGURE 16

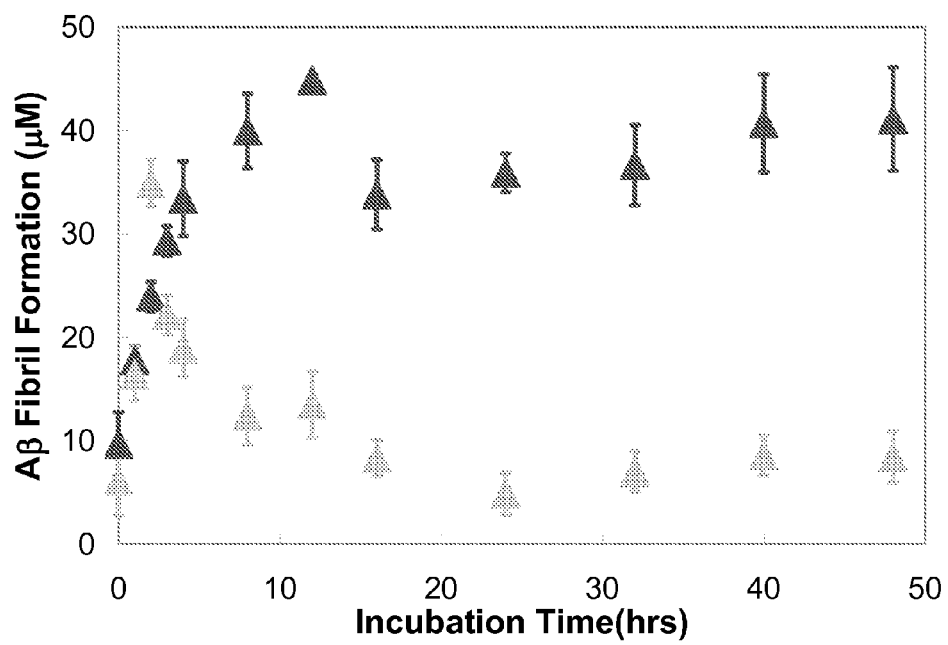
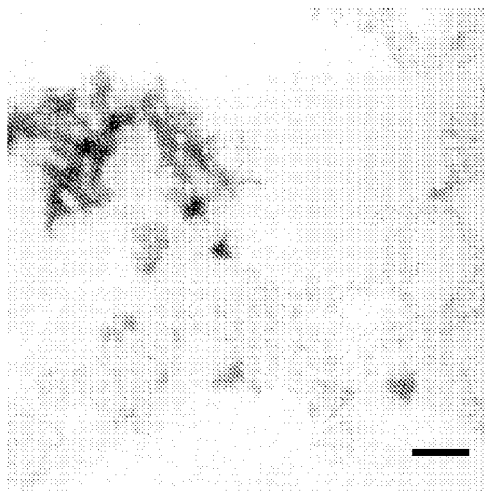


FIGURE 17

B42501 100 mcM HisHSP20 in 100 mcl RT 10mM Pi 120 mM NaCl

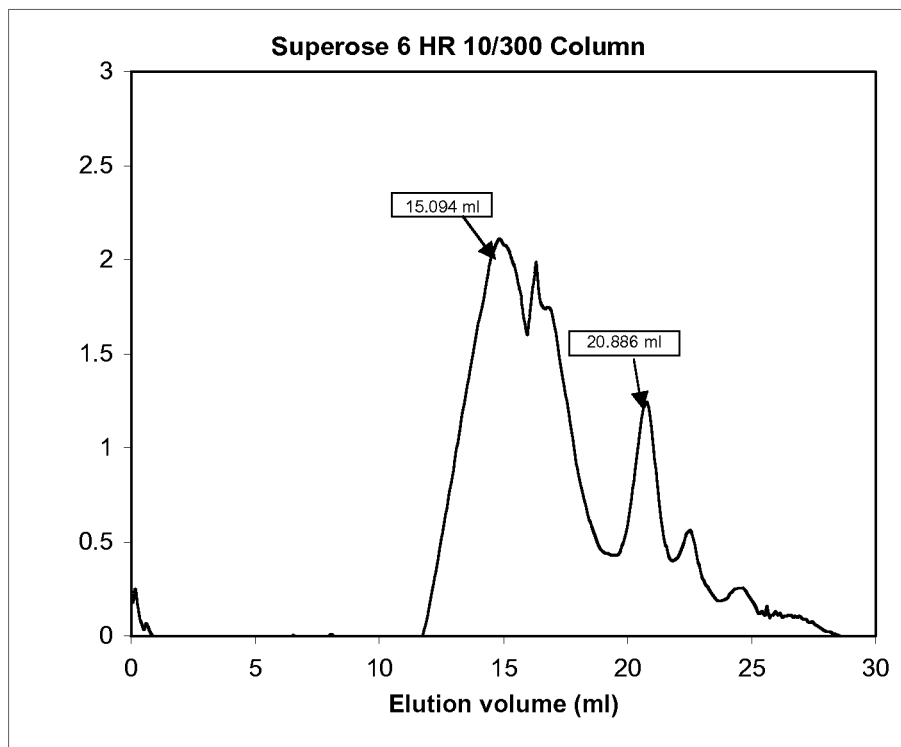


FIGURE 18

D41401 29 mcM HisHSP20 in 100 mcl RT 10mM Pi 500 mM NaCl pH 7.0

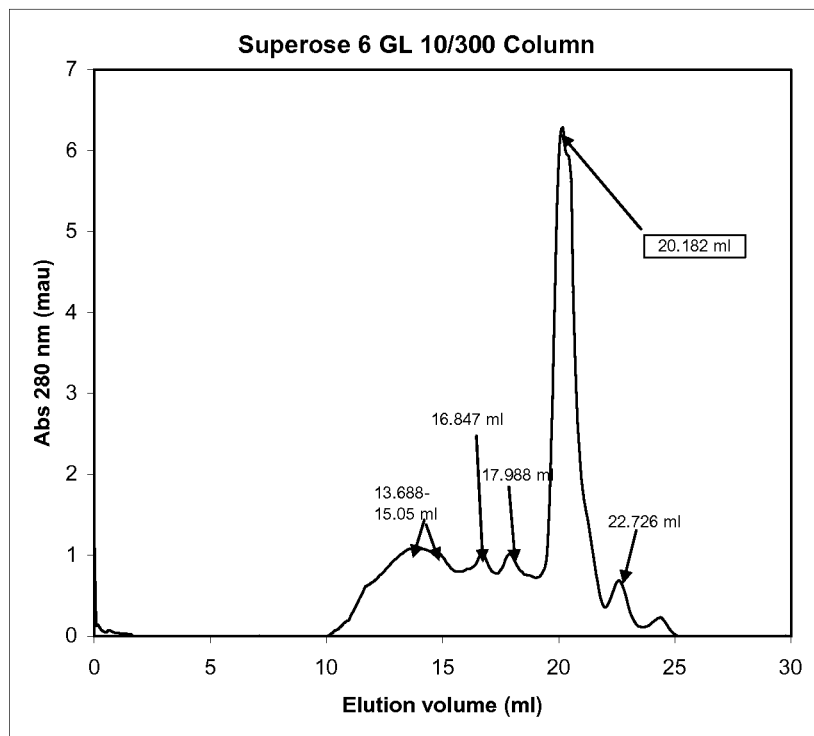


FIGURE 19

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mjannaschiishp 1 MFGRDPFDSLFERMFKEFFATPMTGTTMIQSSTGIQ 36
BBovHSP20aa 1 MSCIMRCNNADQEVIIIDEQTGLPIKSHDYSEKPSVIYKPSTTVPQNTLLE 50
. . . . . * . . . . * . .

mjannaschiishp 37 ISG-K-----GFMPISIIEGDQ---HIKVIAWLPGVNKEDIILNAVGD 76
BBovHSP20aa 51 IPPKELNPITFNPTVDTFADNKNKLVLLMELPGFSSTDINVECGWGE 100
* * * * * * . . . . *** * . .

mjannaschiishp 77 LEIRAKRSPLMITESE-RIIYSEIPEE--EEIYRTIKLPATVKEENASAK 123
BBovHSP20aa 101 LIISGPRNKDELYEKFGNNLDIHIRERKVG YFYRRFKLPNNNAIDKSISVG 150
* * * * * * * * * * * * * * *

mjannaschiishp 124 FENGVL SVILPKAESSIKKGINIE 147
BBovHSP20aa 151 YSNGILDIRIECSQFSEMRRVQIDAKA* 178
. * * . * . . . * . . . *
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FIGURE 20

I41501 50 mM C-Truncated HisHSP20 in 100 mcl RT 10mM Pi 150 mM NaCl pH 7.0

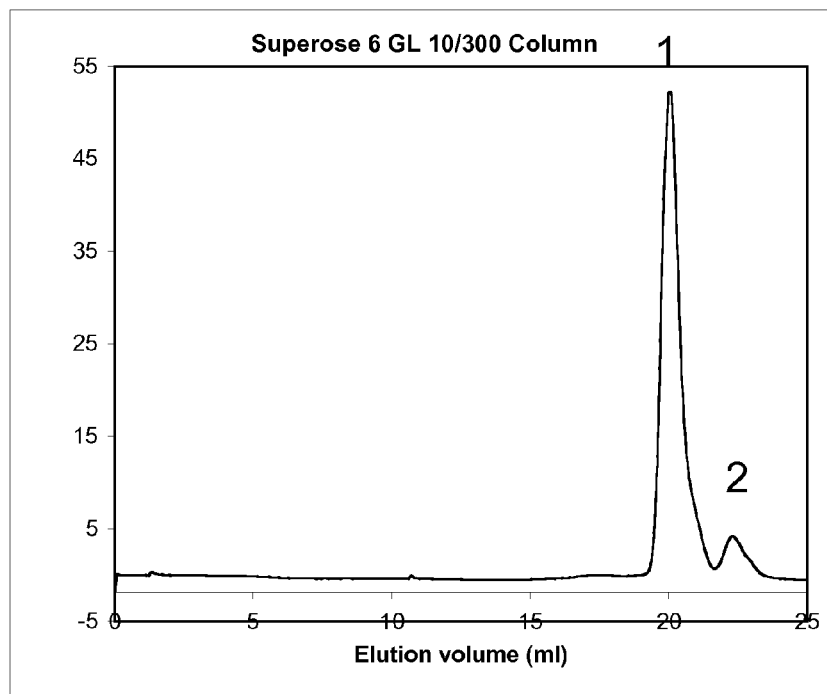


Figure 21

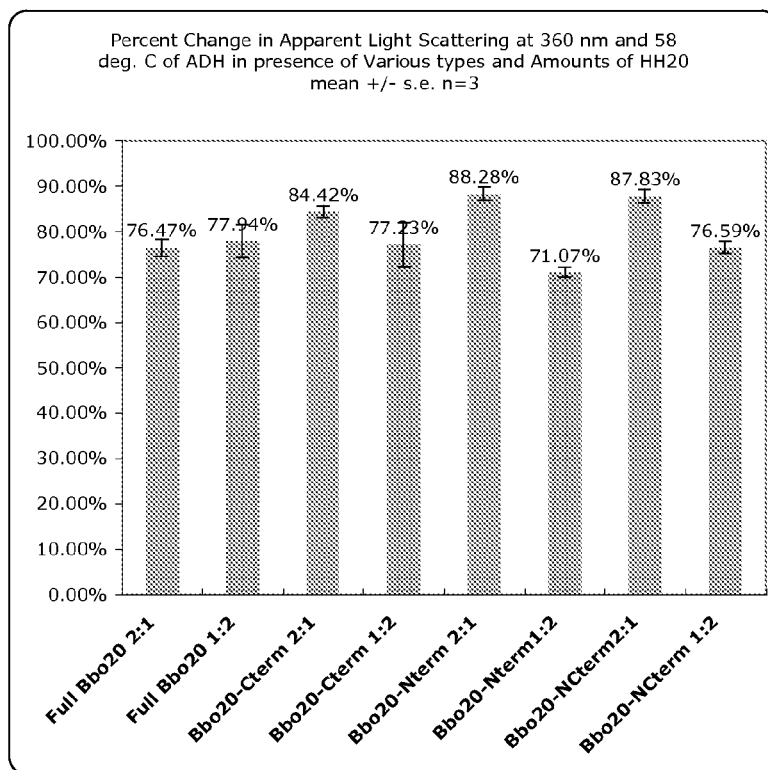


Figure 22

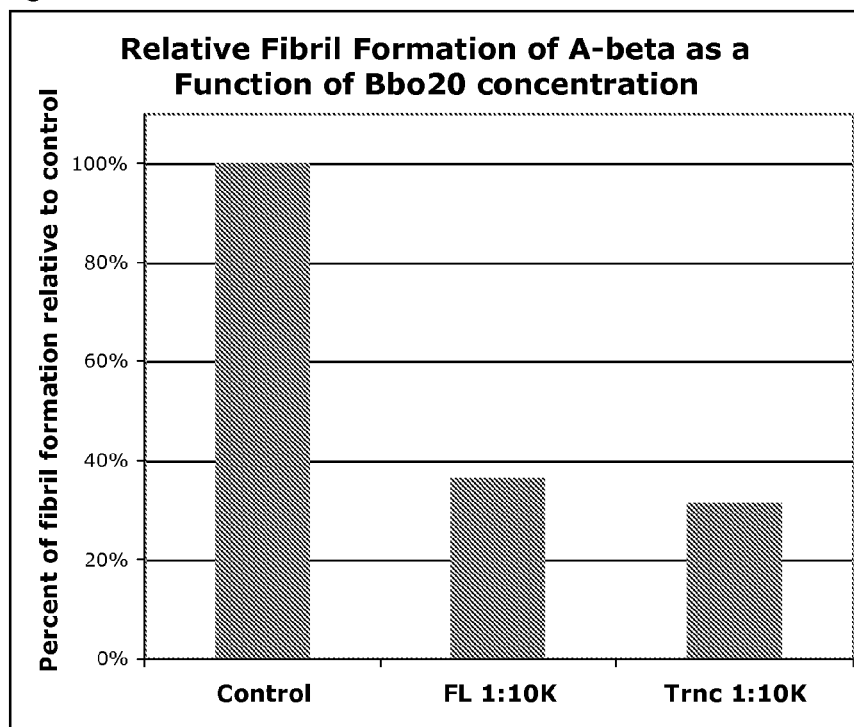


Figure 23

1 MSCIMRCNNADQEVIIIDEQTGLPIKSHDYSEKPSVIYKPSTTVPQNTLLE 50
51 IPPPKELNPITFNPTVDTFDADNNKLVLMLMELPGFSSTDINVECGWGE 100
101 LIISGPRNKDELYEKFNNLDIHIRERKVGIFYRRFKLPNNAIDKSISVG 150
151 YSNGILDIRIECSQFSEMRVQIDAKA 178

1 IPPPKELNPITFNPTVDTFDADNNKLVLMLMELPGFSSTDINVECGWGE 50
51 LIISGPRNKDELYEKFNNLDIHIRERKVGIFYRRFKLPNNAIDKSISVG 100
101 YSNGILDIRIECSQFSEMRVQIDAKA

1 MSCIMRCNNADQEVIIIDEQTGLPIKSHDYSEKPSVIYKPSTTVPQNTLLE 50
51 IPPPKELNPITFNPTVDTFDADNNKLVLMLMELPGFSSTDINVECGWGE 100
101 LIISGPRNKDELYEKFNNLDIHIRERKVGIFYRRFKLPNNAIDKSISVG 150
151 YSNGILDIRIECSQFS

1 IPPPKELNPITFNPTVDTFDADNNKLVLMLMELPGFSSTDINVECGWGE 50
51 LIISGPRNKDELYEKFNNLDIHIRERKVGIFYRRFKLPNNAIDKSISVG 100
101 YSNGILDIRIECSQFS

-42 MGGSHHHHHHGMASMTGGQQMGRDLYDDDDKDPTLENLYFQG His Tag
1 MSCIMRCNNADQEVIIIDEQTGLPIKSHDYSEKPSVIYKPSTTVPQNTLLE 50
51 IPPPKELNPITFNPTVDTFDADNNKLVLMLMELPGFSSTDINVECGWGE 100
101 LIISGPRNKDELYEKFNNLDIHIRERKVGIFYRRFKLPNNAIDKSISVG 150
151 YSNGILDIRIECSQFSEMRVQIDAKA 178

-42 MGGSHHHHHHGMASMTGGQQMGRDLYDDDDKDPTLENLYFQG His Tag
1 IPPPKELNPITFNPTVDTFDADNNKLVLMLMELPGFSSTDINVECGWGE 50
51 LIISGPRNKDELYEKFNNLDIHIRERKVGIFYRRFKLPNNAIDKSISVG 100
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-42 MGGSHHHHHHGMASMTGGQQMGRDLYDDDDKDPTLENLYFQG His Tag
1 MSCIMRCNNADQEVIIIDEQTGLPIKSHDYSEKPSVIYKPSTTVPQNTLLE 50
51 IPPPKELNPITFNPTVDTFDADNNKLVLMLMELPGFSSTDINVECGWGE 100
101 LIISGPRNKDELYEKFNNLDIHIRERKVGIFYRRFKLPNNAIDKSISVG 150
151 YSNGILDIRIECSQFS

-42 MGGSHHHHHHGMASMTGGQQMGRDLYDDDDKDPTLENLYFQG His Tag
1 IPPPKELNPITFNPTVDTFDADNNKLVLMLMELPGFSSTDINVECGWGE 50
51 LIISGPRNKDELYEKFNNLDIHIRERKVGIFYRRFKLPNNAIDKSISVG 100
101 YSNGILDIRIECSQFS

Figure 24

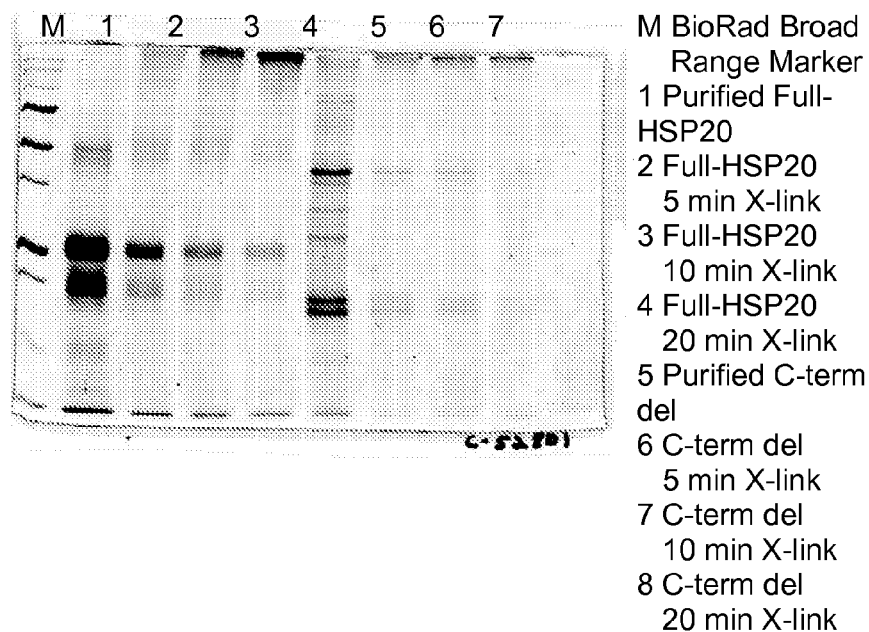


Figure 25

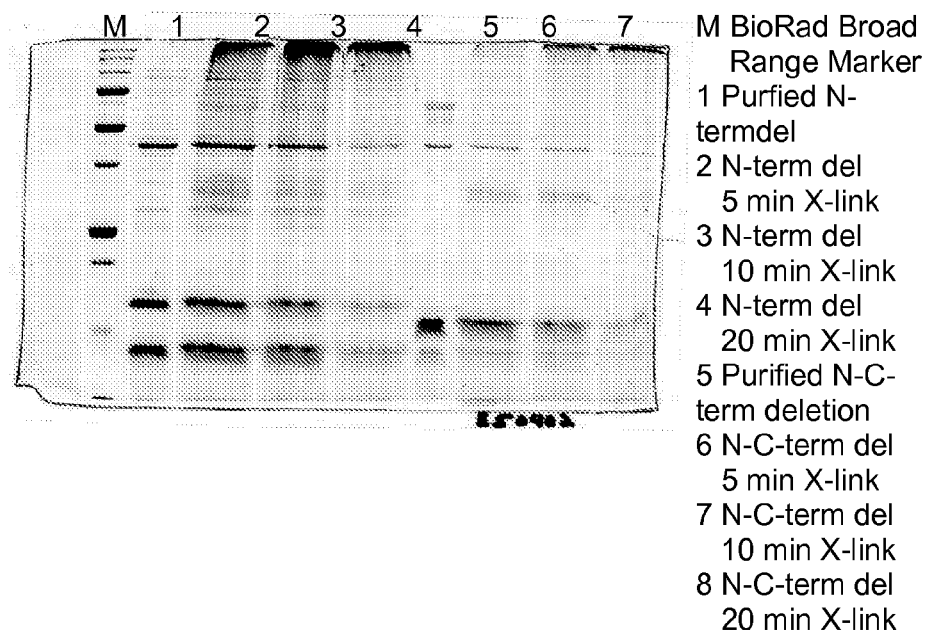


Figure 26

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HSP20 INHIBITS AMYLOIDOGENESIS AND NEUROTOXICITY

This application claims priority to U.S. Provisional Patent Application Ser. No. 60/575,758, filed Mar. 26, 2004, the entire contents of which are incorporated herein by reference.

The U.S. Government may own certain rights in this invention pursuant to the terms of the NSF Grant No. BES-9734496. Without limiting the scope of the invention, its background is described in connection with amyloidogenesis and neurotoxicity.

TECHNICAL FIELD OF THE INVENTION

The present invention relates in general to the field of amyloidogenesis, and more particularly, to a heat shock protein with β -pleated sheets that inhibits amyloidogenesis and neurotoxicity.

BACKGROUND OF THE INVENTION

A number of pathophysiologic diseases have been classified as involving "amyloidosis," which are characterized by the deposition of abnormal fibrils ("amyloid fibrils") in extracellular spaces. The amyloid fibril formation is thought to represent a final common result from the misfolding of a diverse array of proteins. Regardless of their biochemical composition, all types of amyloid fibrils share certain characteristics, including: a β -pleated sheet structure; green birefringence under polarized light after staining with Congo Red dye; and a fibrillar morphology in electron micrographs.

The deposition of amyloid fibrils affects several organs. One type of amyloid fibril causes "cerebral amyloidosis," which covers the Alzheimer group of diseases, namely, Alzheimer's disease (e.g., pre-senile dementia, senile dementia); Alzheimer's disease associated with Down's syndrome; Alzheimer's disease associated with other central-nervous-system diseases, such as Parkinson's disorder; and congophilic angiopathy (whether or not associated with Alzheimer's disease).

Presently, there is no effective therapy for cerebral amyloidosis, which was a fatal outcome following the onset of amyloid deposits. Alzheimer's disease (AD) is estimated to be the fourth or fifth leading cause of death among North Americans. Accumulating biochemical, histological, and genetic evidence supports the hypothesis that the 4 kDa β -amyloid protein ($A\beta$) is an essential component in the pathogenesis of Alzheimer's disease. Selkoe D J, Science 275:630-631 (1997); Hardy J, Proc Natl Acad Sci USA 94:2095-2097 (1997). Despite the intense interest in the role of $A\beta$ in the etiology of AD, the role of $A\beta$ in fibril formation is poorly understood.

SUMMARY OF THE INVENTION

The present inventors have recognized and discovered that Hsp20, a novel α -crystallin isolated from the bovine erythrocyte parasite *Babesia bovis*, is able to prevent aggregation of amyloidogenic proteins. It was found that the α -crystallin isolated and purified from the bovine erythrocyte parasite *Babesia bovis* was able to prevent amyloidogenic target proteins, e.g., β -Amyloid ($A\beta$), from aggregating when the Hsp20 and the target protein were at or near equimolar levels. It was further found that Hsp20 prevented $A\beta$ amyloid formation at a wide range of molar ratios of Hsp20 to $A\beta$, e.g., of about 1:1,000 to 1:200,000. Surprisingly, at higher concentrations of Hsp20, the protein no longer displays its aggrega-

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tion inhibition and toxicity attenuation properties. The development of novel aggregation inhibitors is useful for the treatment of neurodegenerative diseases and disorders, e.g., Alzheimer's, Huntington's, and Parkinson's disease and prion proteins, that involve amyloid toxicity.

More particularly, the present invention includes an isolated and purified polypeptide that includes a portion of an α -crystallin polypeptide having one or more pleated sheets that inhibits neurotoxicity and amyloidogenesis. For example, the polypeptide may be non-human, such as a polypeptide from a bovine erythrocyte parasite. One particular example of a used to prevent neurotoxicity and amyloidogenesis may be at least a portion of an Hsp20 polypeptide from a *Babesia* sp. bovine erythrocyte parasite, e.g., *Babesia bovis*. In one example, the present invention includes both the nucleic acid (SEQ ID NO.: 1) and/or the amino acid sequences of the Hsp20 protein (SEQ ID NO.: 2), truncations and fusion proteins thereof. For example, the Hsp20 polypeptide may include a tag that permits rapid isolation, e.g., a His-tag and even a protease cleavage site, as are well-known to skilled artisans.

The present invention also includes a method of making an α -crystallin polypeptide by culturing a host cell into which a nucleic acid sequence encoding at least a portion of the polypeptide of SEQ ID NO.: 2 has been introduced in transient, selective or permanent form under conditions wherein the host cell expresses the polypeptide and wherein the polypeptide exhibits α -crystallin activity, attenuated neurotoxicity and inhibits amyloidogenesis. An isolated and purified polypeptide may be expressed and isolated by the methods disclosed herein.

One example of a protein for use with the present invention is an isolated and purified, small heat shock protein that includes one or more β -pleated sheets that modulates neurotoxicity over about a one-thousand-fold concentration range by stabilizing an amyloidogenic protein. The concentration range for the activity of the reduction in neurotoxicity of target protein is between about 1 nM to about 5 μ M. In another example, the molar ratio of heat shock protein to amyloidogenic protein may be between about 0.0005 to about 0.001. These proteins may be used in a method of stabilizing a protein with one or more β -pleated sheet by contacting the protein with a heat shock polypeptide with one or more β -pleated sheets wherein the protein remains stable and exhibits attenuated neurotoxicity over a one-thousand-fold concentration range.

The present invention may also be used in a method for stabilizing a protein with a β -pleated sheet in which the target protein is contacted with a heat shock polypeptide that includes one or more β -pleated sheets wherein the protein remains stable over a one-thousand-fold concentration range at a high temperature. The heat shock polypeptide may be an Hsp20 that exhibits α -crystallin activity and inhibits the formation of $A\beta$ multimers such as a parasitic, bacterial, viral, fungal or mammalian analog of Hsp20 that exhibits α -crystallin activity and attenuated toxicity to $A\beta$. The small, heat shock protein (and truncations thereof), may be used in a method of reducing protein aggregation by contacting an aggregation of proteins with an Hsp20 wherein the protein aggregation is reduced. The proteins of the present invention, either with or without a tag, may be used in, e.g., a method of treating a medical condition that exhibits protein aggregation by administering to a subject a physiological effective amount of a heat shock protein with one or more β -pleated sheets, whereby the protein reduces protein aggregation levels in a neuronal tissue of the subject.

The method of preventing protein aggregation disclosed herein includes contacting an amyloidogenic protein with an effective amount of at least a portion of the polypeptide of SEQ ID NO.: 2. The amyloidogenic protein may be in, at or about a tissue, e.g., in, at or about a neural cell. The protein for preventing aggregation includes an isolated and purified portion of a polypeptide having a significant similarity to the α -crystallin family of proteins and one or more β -pleated sheets isolated from *Babesia* sp., e.g., full-length Hsp20, or amino, carboxy, or amino and carboxy terminus truncated Hsp20 protein that inhibits, e.g., A β ₁₋₄₀ fibril formation.

Yet another embodiment of the present invention is a kit or dosage form that includes a first container having an isolated or purified polypeptide with α -crystallin activity and one or more β -pleated sheets that inhibits neurotoxicity and amyloidogenesis. For example, a pharmaceutical composition for treating amyloidogenesis may include an effective amount of at least a portion of a purified polypeptide with α -crystallin activity and one or more β -pleated sheets that inhibits neurotoxicity and amyloidogenesis in pharmaceutically acceptable carrier. One such isolated and purified polypeptide includes an α -crystallin, small, heat shock protein Hsp20 having one or more β -pleated sheets that inhibits neurotoxicity and amyloidogenesis, e.g., one isolated and purified (from the organism or as a recombinant product) from a *Babesia bovis*. The polypeptide may also include a tag for isolation, e.g., an MBP, myc, GST, His-tag and the like.

BRIEF DESCRIPTION OF THE DRAWINGS

For a more complete understanding of the features and advantages of the present invention, reference is now made to the detailed description of the invention along with the accompanying figures and in which:

FIG. 1 is a graph of a turbidity assay used to quantitate the ability of Hsp20 to solubilize target proteins at elevated temperatures;

FIG. 2 is a graph that shows percent reduction of light scattering of various solutions of ADH and Hsp20 relative to ADH alone;

FIG. 3 is a graph of representative Congo Red absorbance spectra;

FIG. 4 is a graph that shows the effect of Hsp20 on reduction of A β fibril formation at different concentrations of A β and Hsp20;

FIGS. 5A to 5C are electron micrographs of A β fibrils, Hsp20, and A β -Hsp20 mixtures, respectively;

FIG. 6 is a graph that plots cell viability as a function of Hsp20 concentration;

FIG. 7 is a graph of turbidity of protein aggregates as a function of time;

FIG. 8 is a nucleic acid sequence of an Hsp20 for use with the present invention (SEQ ID NO.: 1);

FIG. 9 is the amino acid sequence of an Hsp20 (SEQ ID NO.: 2) for use with the present invention in accordance with SEQ ID NO.: 1;

FIG. 10 is a secondary structure prediction of Hsp20;

FIG. 11 is a graph of CD measurements carried out on an AVIV model 62;

FIGS. 12A to 12C show the activities of small heat shock proteins (sHsps) to prevent A β aggregation and toxicity. All protein samples containing A β and sHsps were mixed for 24 hours before aggregation and toxicity assay. Congo red was used as an indicator of A β aggregation and FACS array was used for the biological activities using dye. (12A) 100 μ M A β with His-Hsp20 (solid triangles: Congo red assay, blank triangles: biological activities); (12B) 20 μ M A β with His-

Hsp17.7 (solid circles: Congo red assay, blank circles: biological activities); and (12C) 100 μ M A β with Hsp27 (solid squares—Congo red assay, blank squares—biological activities);

FIG. 13 and FIG. 14 show the kinetics of A β aggregation with sHsps. A β was incubated with or without sHsps and the aggregation rates were detected by FIG. 13 Congo red, and FIG. 14 Turbidity at 405 nm (dark gray diamonds—100 μ M A β , black triangles—100 μ M A β and 0.1 μ M His-Hsp20, gray circles—100 μ M A β and 0.1 μ M His-Hsp17.7, light gray squares—100 μ M A β and 0.1 μ M Hsp27);

FIG. 15 and FIG. 16 show representative electron micrograph images of A β with sHsp. The samples were mixed for 2 hours and then the pictures were taken; (FIG. 15) 100 μ M A β and 0.1 μ M His-Hsp20; (FIG. 16) 100 μ M A β and 0.1 μ M His-Hsp17.7, the length of scale bar is 100 nm;

FIG. 17 is a graph that shows the kinetics of fibril formation in the presence and absence of hsp20 Fibril formation as a function of time in the presence and absence of Hsp20 (100 μ M A β and 100 nM Hsp20 were used; solutions were incubated with mixing at 37° C. and fibril formation was determined using Congo red binding);

FIG. 18 shows the dynamic relationship of the oligomeric states of hsp20 using FPLC analysis of 29 μ M hsp20 in 500 mM NaCl (13.69=16mer; 15.05=10mer; 16.85=hexamer; 17.99=tetramer; 20.18=dimer; 22.72=monomer Dimer=15% of total);

FIG. 19 is a graph that shows the dynamic relationship of the oligomeric states of hsp20;

FIG. 20 is a sequence alignment of M.j-sHSP and *B. bovis* HSP20: N terminal and C terminal deletions with the C-terminal deletion of HSP20=EMRRVQIDAKA (SEQ ID NO.: 5);

FIG. 21 is a graph of the size distribution of truncated Hsp20 (tHsp20);

FIG. 22 shows that truncated hsp20 blocks ADH denaturation;

FIG. 23 is a graph that shows that fibril formation of A β peptide in the presence of full length and truncated hsp20.

FIG. 24 includes the amino acid sequences for the full length, amino terminal truncated, carboxy terminal truncated, both the amino and carboxy terminal truncated, a his-tagged full length, a his-tagged amino terminal truncated, a his-tagged carboxy terminal truncated, and a his-tagged the amino and carboxy terminal truncated protein;

FIG. 25 is a gel that shows the effect of the truncations (as listed) on the target protein, and that the monomeric protein is depleted over time indicating its role in multimer formation; and

FIG. 26 is a gel that shows the effect of the truncations (as listed) on the target protein, and that the monomeric protein is depleted over time indicating its role in multimer formation.

DETAILED DESCRIPTION OF THE INVENTION

While the making and using of various embodiments of the present invention are discussed in detail below, it should be appreciated that the present invention provides many applicable inventive concepts that can be embodied in a wide variety of specific contexts. The specific embodiments discussed herein are merely illustrative of specific ways to make and use the invention and do not delimit the scope of the invention.

To facilitate the understanding of this invention, a number of terms are defined below. Terms defined herein have meanings as commonly understood by a person of ordinary skill in the areas relevant to the present invention. Terms such as “a”,

“an” and “the” are not intended to refer to only a singular entity, but include the general class of which a specific example may be used for illustration. The terminology herein is used to describe specific embodiments of the invention, but their usage does not delimit the invention, except as outlined in the claims.

β -Amyloid ($A\beta$) is a major protein component of senile plaques in Alzheimer's disease, and is neurotoxic when aggregated. The size of aggregated $A\beta$ responsible for the observed neurotoxicity and the mechanism of aggregation are still under investigation; however, prevention of $A\beta$ aggregation still holds promise as a means to reduce $A\beta$ neurotoxicity. Alzheimer's disease (AD), the leading cause of dementia in the aging population, is accompanied by the accumulation of β -amyloid peptide ($A\beta$) as amyloid fibrils in senile plaques in the cerebral cortex. It is suggested by many that $A\beta$ contributes to the neurodegeneration associated with AD via the toxicity of the peptide in aggregated form.

The superfamily of small heat shock proteins, sHSPs, are a diverse group of proteins involved in prevention of protein misfolding and the onset of programmed cell death (16, 17). They typically exist as large multimeric complexes containing 4 to 40 subunits, with molecular masses of 40 kDa or less per subunit. The sHSPs bind to their substrates with high affinity and prevent protein misfolding in an ATP independent reaction (18). Generally, the α -crystallins are considered to be sHSPs (15, 19). Circular Dichroism spectroscopy (CD) studies predict that β -pleated sheet dominates the secondary structure of the α -crystallins (20, 21). A conserved 90 amino acid sequence, located near the C-terminus, termed the α -crystallin domain, is the hallmark of all α -crystallins.

Other small heat shock proteins and α -crystallins have been examined for their ability to prevent $A\beta$ and other amyloid fibril formation, with good success at relatively low molar ratios of α -crystallin to amyloid (11, 12, 22, 23). However, in none of these studies has toxicity inhibition been reported. Indeed, in work reported by others (12), α B-crystallin prevented $A\beta$ fibril formation but enhanced toxicity. The Hsp20 protein reported herein, both reduces $A\beta$ fibril formation at very low molar ratios, and reduces $A\beta$ toxicity at similar molar ratios.

The present inventors have recognized and discovered that Hsp20, a novel α -crystallin isolated from the bovine erythrocyte parasite *Babesia* sp., e.g., *Babesia bovis*, is able to prevent aggregation of amyloidogenic proteins. Other members of the *Babesia* family, e.g., *Babesia bigemina*, also express Hsp20 with very high amino acid sequence conservation. It was found that the α -crystallin isolated and purified from the bovine erythrocyte parasite *Babesia bovis* prevented denaturation of alcohol dehydrogenase when the two proteins are present at near equimolar levels. The same assay may be used to initially screen other species. Next, the ability of Hsp20 to prevent $A\beta$ amyloid formation was investigated using Congo Red binding. It was found as demonstrated herein that not only is Hsp20 able to dramatically reduce Congo Red binding, but it was also able to do so at molar ratios of Hsp20 to $A\beta$ of 1 to 1000. Electron microscopy confirmed that Hsp20 does prevent $A\beta$ fibril formation. Hsp20 was also able to significantly reduce $A\beta$ toxicity to both SH-SY5Y and PC12 neuronal cells at similar molar ratios. Surprisingly, at higher concentrations of Hsp20, the protein no longer displays its aggregation inhibition and toxicity attenuation properties. The development of novel aggregation inhibitors is useful for the treatment of neurodegenerative diseases and disorders, e.g., Alzheimer's disease, that involve amyloid toxicity.

Investigation of the relationship between aggregated $A\beta$ peptide size, structure and toxicity is ongoing. In an aggre-

gated state containing fibrils, protofibrils, and low molecular weight intermediates/oligomers, $A\beta$ peptide has proven to be toxic to cultured neuronal cells (1, 2). $A\beta$ structures reported to be toxic include a non-fibrillar species of approximately 17 to 42 kDa (1), protofibrils species with hydrodynamic radii on the order of 6 to 9 nm (3) and 22-35 nm or 97-367 nm (4) and fibril species, with some investigators suggesting that the smaller oligomeric $A\beta$ species are more toxic than fibril and protofibril forms (5). Many believe that one strategy for preventing neurodegeneration associated with AD is the prevention of aggregation of $A\beta$ into its toxic oligomeric or fibril forms.

Inhibitors of $A\beta$ aggregation have been investigated with the aim of preventing AD toxicity (6-9). Some of these inhibitors are small peptides with sequences that mimic the sequence of AD believed to be essential for aggregation and fibril formation (8). Peptide inhibitors of this class have been able to prevent $A\beta$ toxicity by altering the aggregated structure when added at inhibitor to $A\beta$ molar ratios of 1:1 (8, 10). The use of molecular chaperones including α -crystallins and other small heat shock proteins has also been explored as a means of preventing $A\beta$ aggregation and toxicity. For example, human sHsp27 inhibited $A\beta$ 1-42 fibril formation (11). When α B crystallin was examined, it was actually found to increase toxicity and β pleated sheet content of $A\beta$ 1-40 although it prevented fibril formation of $A\beta$ in vitro at inhibitor to $A\beta$ molar ratios of 1:1 or 1:5 (12).

The present invention is a novel small heat shock protein, Hsp20, isolated from the erythrocyte parasite *Babesia bovis* to prevent aggregation of $A\beta$ and $A\beta$ toxicity. It is shown herein that Hsp20 has α -crystallin-like properties, and that it prevents aggregation of denatured alcohol dehydrogenase. Hsp20 also prevents amyloid formation of $A\beta$ as indicated by Congo Red binding at molar ratios of Hsp20 to $A\beta$ of 1:1000. Hsp20 attenuated the toxicity of $A\beta$ in SH-SY5Y and PC12 neuronal cells at analogous molar ratios. Furthermore, Hsp20 appears to be able to prevent $A\beta$ aggregation via a novel mechanism and at much lower concentrations than what has been necessary to prevent aggregation with other inhibitors. Hsp20 may be a useful molecular model for the design of the next generation of $A\beta$ aggregation inhibitors to be used in the treatment of AD.

Materials. $A\beta$ (1-40) was purchased from Biosource International (Camarillo, Calif.). Cell culture reagents were purchased from GibcoBRL (Grand Island, N.Y.). All other chemicals were obtained from Sigma (St. Louis, Mo.) unless otherwise stated. His-tagged-Hsp20 was produced and isolated in *E. coli*. Previously, Hsp20 had been made as a fusion protein with Maltose binding protein (MBP), however, it was found that the MBP-Hsp20 did not show the effects described and claimed herein (13).

$A\beta$ Peptide Preparation. Stock solutions of 10 mg/ml $A\beta$ (1-40) peptides were dissolved in 0.1% (v/v) trifluoroacetic acid (TFA) in water. After incubation for 2030 min. at 25° C., the peptide stock solutions were diluted to concentrations of 0.5 mg/ml by addition of sterile phosphate buffered saline (PBS; 0.01 M NaH_2PO_4 , 0.15 M NaCl, pH 7.4). The peptides were diluted to final concentrations of 20 μM , 50 μM , and 100 μM by addition of PBS for Congo Red and electron microscopy (EM) studies. Cell culture medium (below) replaced PBS in toxicity studies. These solutions were rotated at 60 revolutions per minute at 25° C. for 24 hours to ensure aggregation.

Cell Culture. Human neuroblastoma SH-SY5Y cells (obtained from Dr. Evelyn Tiffany-Castiglioni, College of Veterinary Medicine, Texas A&M University, College Station, Tex.) were cultured in minimum essential medium (MEM)

supplemented with 10% (v/v) fetal bovine serum (FBS), 3 mM L-glutamine, 100 U/ml penicillin, 100 µg/ml streptomycin, and 2.5 µg/ml amphotericin B (fungizone) in a humidified 5% (v/v) CO₂/air environment at 37° C. Rat pheochromocytoma PC12 cells (ATCC, Rockville, Md.) were cultured in RPMI medium supplemented with 10% (v/v) horse serum, 5% (v/v) FBS, 3 mM L-glutamine, 100 U/ml penicillin, 100 µg/ml streptomycin, and 2.5 µg/ml fungizone in a humidified 5% (v/v) CO₂/air environment at 37° C. For the toxicity assays, cells were plated at a density of 1×10⁵ cells/well in 96 well plates and aggregated peptide solutions were added to the cells 24 hours after plating.

Congo Red Binding. Congo Red studies were performed to assess the presence of amyloid fibrils in Aβ solution. Congo Red dye was dissolved in PBS to a final concentration of 120 µM. Congo Red solution was added to the peptide solutions at the ratio of 1:9. The peptide solution and control solution were allowed to interact with Congo Red for 3040 minutes prior to absorbance measurement with a Model 420 UV-Vis spectrophotometer (Spectral Instruments, Tucson, Ariz.) at 25° C. The fibril formation of the samples was estimated from the absorbance using equation (1);

$$[A\beta_{Fib}] = \left(\frac{A_{541}}{A_{4780}} \right) - \left(\frac{A_{403}}{A_{CR/8620}} \right) \quad (1)$$

where $[A\beta_{Fib}]$ is the concentration of Aβ fibril, A_{541} , A_{403} , and A_{CR} are the absorbances of the sample and Congo Red at the wavelength of 541 nm and 403 nm, respectively (14). From these data, relative fibril concentrations were calculated as the ratio of sample fibril concentration to pure Aβ fibril concentration.

MTT Reduction Assay. Cell viability was measured 24 hours after peptide addition to cells using the 3, (4,5-dimethylthiazol-2-yl) 2,5-diphenyl-tetrazolium bromide (MTT) reduction assay. 10 µl of 12 mM MTT was added to 100 µl of cells plus medium in a 96 well plate. The cells were incubated with MTT for 4 hours in a CO₂ incubator. Then, 100 µl of a 5:2:3 N,N-dimethylformamide (DMF): sodium dodecyl sulfate (SDS): water solution (pH 4.7) was added to dissolve the formed formazan crystals. After 18 hours of incubation in a humidified CO₂ incubator, the results were recorded by using an Emax Microplate reader at 585 nm (Molecular Devices, Sunnyvale, Calif.). Percentage cell viability was calculated by comparison between the absorbance of the control cells and that of peptide or peptide:Hsp20 treated cells. Relative cell viability increase, was calculated from the ratio of the difference in cell viability of Hsp20:Aβ treated cells and cells treated with pure Aβ, divided by viability of cells treated with pure Aβ.

Electron Microscopy (EM). 200 µl of Aβ peptide solution, prepared as described above, was mixed, placed on glow discharged grids, and then negatively stained with 1% aqueous ammonium molybdate (pH 7.0). Grids were examined in a Zeiss 10C transmission electron microscope at an accelerating voltage of 80 kV. Calibration of magnification was done with a 2,160 lines/mm crossed line grating replica (Electron Microscopy Sciences, Fort Washington, Pa.).

Turbidity Assay. ADH Turbidity Assay. Light Scattering of ADH and Hsp20 was performed as previously described (15). Briefly, the aggregation of ADH and Hsp20 in solution was measured by the apparent absorption due to scattering at 360 nm in a Gilford Response II spectrophotometer at 58° C. Solutions were mixed at room temperature in 50 mM phosphate buffer, pH 7.0 and analyzed immediately. 1.625 µM ADH was used in all studies. Hsp20 concentrations were varied to obtain different molar ratios of Hsp20 to ADH. Absorbance readings were taken at 1 minute intervals for one hour.

Aβ Turbidity Assay. Aβ samples were prepared as described for other studies, however, aggregation took place without mixing at 4° C. These conditions were chosen to slow down the rate of aggregation. Hsp20 was added to Aβ samples either at the beginning of incubation or after 6 days (a time insufficient for large changes in turbidity to be observed). Turbidity was determined by measuring sample absorbance at 400 nm on the UV-vis spectrophotometer.

Statistical analysis. For each study, at least 3 independent determinations were made. Significance of results was determined via the student t test with p<0.05 unless otherwise indicated. Data are plotted as the mean plus or minus the standard error of the measurement.

Characterization of Hsp20. Hsp20 is a 177 amino acid, 20.1 kDa protein isolated from *Babesia* sp., specifically *Babesia bovis*, a protozoan bovine erythrocyte parasite (13). Initial characterization by BLAST search of the NCBI database indicated sequence similarity with the α-crystallin family of small heat shock proteins. Hsp20 contains a region near its C-terminus that corresponds to the 95 amino acid α-crystallin domain common to members of this protein family. These proteins are thought to be involved in the cellular response to stress. Previous work (Ficht, unpublished observation) has revealed that Hsp20 expression is up-regulated in times of thermal, nutritional and oxidative stress to the organism. Based on the apparent involvement of Hsp20 in the stress response coupled with its homology to the α-crystallins, α-crystallin activity assays were applied to Hsp20.

For the His-Tag Hsp20 expression construct, the following primers were used: Primer: F32901FT forward primer for hsp20 with Tobacco Etch Virus (TEV) protease site immediately upstream:

(SEQ ID NO.: 3)
5' - GAA AAT CTT TAT TTT CAA GGT ATG TCG TGT ATT
ATG AGG TGC - 3';

The first seven (7) codons encode the TEV protease site, the last seven (7) codons are the beginning of the hsp20 coding sequence:

Primer: F32901RT Reverse primer for hsp20 with in-frame stop:

(SEQ ID NO.: 4)
5' - CTA TTA GGC CTT GGC GTC AAT CTG AAC - 3';

These primers were used to PCR a 621 coding region.

Ligation/Transformation of above insert. The Invitrogen protocol pTrcHis and pTrcHis2 TOPO TA Expression Kits Version I were used to ligate and transform the PCR product, relevant portions and solutions incorporated herein by reference. The PCR reactions were incubated directly with the TOPO plasmid according to the manufacture's protocol. This resulted in ligation of the PCR product into the pTrcHis vector. Transformed vector into chemically competent TOP10 cells (Invitrogen) and screened on LB/amp50 plates.

Directional PCR of transformants to screen for possible clones. The ProBond Purification System protocol version I from Invitrogen was used. The Hybrid protocol was modified and used to purify Hsp 20 from the lysate. Cells were grown to OD600 of 0.5 and induced with 1 mM IPTG for 5 hours, spun down and the removed media. The cells were lysed in PBS using a French pressure cell, the lysate centrifuged and the supernatant removed. The pellet containing hsp20 was suspended in Denaturing Binding Buffer (in accordance with

manufacturer's instructions, relevant portions and solutions incorporated herein by reference) containing 8M urea.

Hybrid purification procedure. Briefly, resin was washed with buffer containing 8M urea. Incubated resin with lysate pellet in 8M urea for one hour. The resin was washed with denaturing buffer and then washed with native wash buffer (no urea). Next, the protein was eluted from the resin using 100 mM EDTA in water. Dialyzed over night into PBS pH 7.0. At this point, the protein can be stored at either 4 or 25 deg. C. Frozen samples are first diluted with glycerol (20% final).

FIG. 1 is a graph of a turbidity assay used to quantitate the ability of Hsp20 to solubilize target proteins at elevated temperatures. Turbidity was measured using Light scattering of ADH, as determined by absorbance at 360 nm, at elevated temperature in the presence and absence of Hsp20. ADH at a concentration of 1.625 μ M is incubated in phosphate buffer alone (open circles) and in the presence of 5.75 μ M Hsp20 (closed triangles) at 58° C. for one hour.

A solution of alcohol dehydrogenase when incubated at 58° C. for 60 minutes exhibits a dramatic increase in light scattering due to denaturation of the enzyme. When Hsp20 was included in the solution at time zero in a molar ratio of 2:1 Hsp20:ADH, a 2.3 fold reduction in light scattering is observed at 60 minutes. To determine the most effective molar ratio for the reduction of light scattering, a series of studies applying different molar ratios was conducted.

FIG. 2 is a graph that shows percent reduction of light scattering at time infinity of various solutions of ADH and Hsp20 relative to ADH alone. The greatest reduction in light scattering was observed at 2:1 molar ratio (Hsp20:ADH). All studies were performed at 58° C. ADH was included at 1.625 μ M in each study. Light scattering at time infinity was estimated from absorbance versus time curves for each mixture. At time infinity (as determined by curve fitting software), the greatest reduction in light scattering is seen at a molar ratio of 2:1 (Hsp20 to ADH). Having established the α -crystallin activity of Hsp20 based standard assays, the ability of Hsp20 to affect A β (1-40) fibril formation was determined.

Effect of Hsp20 on A β Fibril Formation Prevention. Given that Hsp20 was able to prevent aggregation of denatured ADH, its ability to prevent aggregation and amyloid fibril formation of A β (1-40) was determined. Congo Red binding was used as an indicator of amyloid formation. In these studies 150 μ M concentrations of A β (1-40) were used to create fibrils. Hsp20 at concentrations from 50 μ M to 2.5 μ M were added to A β (1-40) solutions prior to aggregation. This corresponds to molar ratios of Hsp20 to A β of 1:1,000,000 to 1:20. After 24 hours of incubation, sufficient time for typical fibril formation, Congo Red was added to samples to assess fibril formation.

FIG. 3 is a representative absorbance spectra of Congo Red with A β and A β -Hsp20 mixtures. 100 μ M A β (1-40) was used in all cases. Hsp20 was added at the beginning of the 24 hour aggregation at room temperature with mixing. Hsp20 alone did not alter Congo Red absorbance. Pure A β (1-40) solutions caused a characteristic shift in absorbance to longer wavelengths and an increase in intensity. Hsp20, when added to A β prior to aggregation, attenuated the shift in absorption and increase in intensity associated with A β fibril formation.

FIG. 4 is a graph that summarizes the effects of Hsp20 on reduction of A β fibril formation at different concentrations of A β and Hsp20. At Hsp20 concentrations below 0.1 μ M, A β fibril formation decreased as a function of Hsp20 concentration. However, Hsp20 became less effective at preventing A β fibril formation in the higher concentration range. The concentration of Hsp20 needed for optimal prevention of fibril

formation appeared to be a function of A β concentration, with the lowest concentration of A β exhibiting the optimum in prevention of fibril formation at the lowest Hsp20 concentration. Fibril formation is reported relative to fibril formation seen with pure A β solutions. Mean plus or minus standard deviation of at least 3 independent studies are shown (open circles—20 μ M A β ; squares—50 μ M A β ; triangles—100 μ M A β).

The optimum in fibril formation for the concentration of A β tested occurred at the molar ratios between 0.000005 and 0.001 of Hsp20 to A β . The molar ratio of Hsp20 to A β needed to optimally prevent fibril formation is several orders of magnitude lower than that needed to prevent aggregation of ADH.

FIGS. 5A to 5C are electron micrographs of A β fibrils, Hsp20, and A β -Hsp20 mixtures that correspond to conditions used in the Congo Red binding studies. These representative electron micrographs of A β and Hsp20 were taken after 24 hours of aggregation (5A) 100 μ M A β , (5B) 0.1 μ M Hsp20, and (5C) 100 μ M A β +0.1 μ M Hsp20. In the images, 100 μ M A β and 0.1 μ M Hsp20 were used. As seen in FIG. 5A, A β formed long individual fibrils and groups of long fibrils under the aggregation conditions employed. Hsp20, at 0.1 μ M and room temperature, formed species of approximately 13.6 nm in diameter, composed of 2 subunits, 5.4 nm in width each, with a distance of 2.7 nm between subunits (FIG. 5B). In micrographs of the A β -Hsp20 mixture (FIG. 5C), small globular species with a 16.3 nm diameter and variable length were observed. These species could be an Hsp20-A β complex, large Hsp20 aggregates, and/or A β -protofibrils. A β fibrils were noticeably absent from micrographs of A β -Hsp20 mixtures.

Ability of Hsp20 To Prevent Toxicity of A β . A β is typically toxic to neuron-like cells (SY5Y cells, and PC12 cells etc.) when in aggregated form. The effect of Hsp20 on A β toxicity was measured using the MTT assay for 100 μ M A β added to SH-SY5Y cells and 2 μ M A β added to PC12 cells.

FIG. 6 is a graph that plots cell viability as a function of Hsp20 concentration. In FIG. 6, the relative cell viability of SY5Y cells (triangles) and PC12 cells (circles) treated with 100 μ M (triangles) and 2 μ M (circles) A β as a function of Hsp20 concentration is shown. Viability was measured via the MTT reduction assay. N is greater than or equal to 6. A β (1-40) was incubated for 24 hrs in the media prior to addition to the cells. Viability as a function of molar ratio of Hsp20 to A β ; viability is reported relative to A β treated cells. Hsp20 by itself had no effect on SH-SY5Y or PC12 cell viability. However, Hsp20, when added to A β prior to aggregation, had a profound effect on A β toxicity observed in both cell types. It appears that the two viability curves as a function of Hsp20 to A β molar ratio are superimposed. The molar ratio of Hsp20 to A β needed for optimal toxicity attenuation is approximately the same as the molar ratio needed for optimal fibril formation prevention.

Ability of Hsp20 to reverse A β aggregation. In studies parallel to those described above, the ability of Hsp20 to reverse fibril formation, once A β was aggregated, was determined. Under conditions analogous to those described previously, and after 24 hours of A β aggregation, Hsp20 was added at optimal concentrations to prevent fibril formation (100 nM), incubated for up to 2 days, and then assessed fibril content via Congo Red binding. At all time points measured, fibril formation after addition of Hsp20 was equal to or greater than fibril formation of A β alone after 24 hours aggregation (data not shown). In all cases, viability of SH-SY5Y cells, as measured by the MTT assay, treated with solutions in which Hsp20 was added after 24 hour A β aggregation was not

significantly greater than viability of cells treated with A β that had been allowed to aggregate for 24 hours (data not shown).

Ability of Hsp20 to prevent later steps in A β aggregation. In order to assess if Hsp20 could prevent A β aggregation, even if added after the beginning of aggregation, a second set of aggregation conditions was developed in which initial aggregation events (such as fibril nucleation) may occur more slowly. 100 μ M A β were allowed to aggregate at 4° C. without mixing and measured aggregation via changes in turbidity of the A β solution.

FIG. 7 is a graph of turbidity of protein aggregates as a function of time. A β was allowed to aggregate under these conditions, a rapid rise in turbidity was observed after 6 days incubation. Samples are incubated at 4° C. without rotation (closed circles—100 μ M A β (no Hsp20); open circles). Hsp20 was added to 100 μ M A β at the beginning of A β incubation: triangles—Hsp20 addition to 100 μ M A β at 6 day after A β incubation.

When Hsp20 was added (final concentration of 100 nM) at the beginning of aggregation, no dramatic increase in turbidity was observed. These results are consistent with Congo Red and electron microscopy results obtained under rapid aggregation conditions. Similarly, when Hsp20 (final concentration of 100 nM) was added to the A β solutions at day 6, again no dramatic increase in turbidity was observed.

Electron micrographs of samples prepared under slow A β aggregation conditions clearly indicated the presence of fibrils both in the presence and absence of Hsp20, however, possibly less lateral fibril aggregation was observed in solutions containing Hsp20 (micrographs not shown).

Toxicity of A β solutions prepared via slow aggregation (at 4° C. without mixing) with and without Hsp20, was measured. In all cases, toxicity was largely unchanged upon addition of Hsp20, regardless of when Hsp20 was added in the aggregation process (data not shown).

The Hsp20 isolated, purified and characterized herein from the bovine erythrocyte parasite *Babesia bovis* (13) was demonstrated to have α -crystallin activity in vitro. The apparent light scattering of alcohol dehydrogenase in solution at 58° C. is reduced when in the presence of equimolar concentrations of recombinant Hsp20 (FIG. 1). This indicates reduced aggregation of denatured ADH at the elevated temperature due to an interaction with Hsp20. The optimal Hsp20 to ADH binding ratio is 2:1 (FIG. 2), consistent with the stoichiometry of binding one Hsp20 dimer to one ADH molecule. This is consistent with the observations of van Montfort et al (20) that other alpha crystallins are active as dimers. In addition, Hsp20 is upregulated under heat shock conditions (42° C.) and oxidative stress (molecular O₂ and H₂O₂); and, as other α -crystallins, it also forms higher order complexes as revealed through dynamic light scattering analysis (unpublished observation). Hsp20 has limited nucleotide and amino acid sequence homology to members of the α -crystallin family, with the majority of the identical/conserved amino acids occurring in the region corresponding to the α -crystallin domain (13). The α -crystallin-like activity and ability to prevent protein aggregation of Hsp20 indicate that it may be potentially useful as an aggregation inhibitor (or a model for an aggregation inhibitor) for A β . In view of its divergent sequence, this α -crystallin may have entirely unique properties.

As show herein in FIGS. 3-5A-5C, that Hsp20 prevents ADH fibril formation as indicated by the absence of Congo Red binding and of visible fibrils in electron micrographs, at molar ratios near 1:1000 Hsp20 to A β . This is in sharp contrast to the near 1:1 (2:1, or even 4:1 if ADH is considered a dimer) molar ratio needed to prevent ADH aggregation. A number of inves-

tigators have explored the ability of other small heat shock proteins, molecular chaperones, and α -crystallins to prevent fibril formation in several systems including A β (11, 12, 22, 23). Most have found that the chaperones or small heat shock proteins can inhibit A β aggregation at molar ratios of chaperone to A β of 1:10 to 1:100. The low concentrations of Hsp20 and other α -crystallins needed to prevent fibril formation, relative to that needed to prevent ADH aggregation, could be related to specificity of the α -crystallins for β -sheet or fibril forming proteins. Alternatively, the difference in molar ratios needed to prevent ADH aggregation relative to those needed to prevent A β fibril formation may be related to the temperature differences at which the studies were carried out. The ADH aggregation studies were carried out at elevated temperature, while the A β fibril formation studies were carried out at room temperature. The quaternary structure of α -crystallins are generally temperature dependent; however, most often, more highly active oligomers (dimers) are formed at higher temperatures (20, 24).

Hsp20 may interact with an oligomer of A β in a near 1 to 1 molar ratio; however, the A β oligomer may be very dilute in A β solutions. In models of A β aggregation, investigators postulate that A β forms micelles or multimeric nuclei from A β monomers or dimers via a high order process (25-27). It is from these micelles or nuclei that fibril growth is initiated. Micelles or nuclei would be far less abundant than monomeric A β . Hsp20 binding may lead to removal of fibril initiating species from solution, thereby preventing A β fibril formation.

As seen in FIG. 4, there is an optimum concentration of Hsp20 for A β fibril formation prevention. Oligomerization dynamics of α -crystallins are concentration dependent (28). Hsp20 may aggregate to form a less active structure at higher concentrations. High molecular weight oligomers of heat shock proteins, which tend to form at high concentrations, are less active than the low molecular weight oligomers (29). Additionally, equilibrium distribution of oligomeric Hsp20 species are likely to dependent upon conformers or oligomers of substrate A β present in solution.

Analogous to fibril formation prevention data, Hsp20 attenuates A β toxicity at similar molar ratios (FIG. 6). These data suggest that the A β species which bind Congo Red and have fibril appearance on electron micrographs are toxic. Non-fibrillar ADDLs, low molecular weight oligomers, protofibrils, and fibrils have all been found to be toxic (1, 3). In some cases oligomeric A β has been found to be more toxic than fibril A β (5). These results suggest that addition of Hsp20 leads to a reduction in the formation of some of these species.

A careful examination of electron micrographs of A β -Hsp20 mixtures under optimal fibril formation and toxicity prevention conditions (FIG. 5A-5C) reveals the presence of small globular species with a 16.3 nm diameter and variable length. Size analysis of these globular structures suggests that the species may be an Hsp20-A β complex rather than A β protofibrils since the width of these species (16.3 nm) is atypical for A β micelles (5-11 nm), protofibrils (4-8 nm), or fibrils (6-10 nm) (27).

When A β was aggregated slowly at 4° C., Hsp20 was able to prevent large increases in turbidity when added to A β at a 1:1000 molar ratio of Hsp20 to A β (FIG. 7). Electron micrographs of species formed indicate that under these conditions Hsp20 prevented some lateral aggregation of fibrils but did not prevent fibril formation. In addition, with slow aggregation, Hsp20 did not prevent toxicity. Thus, lateral aggregation of fibrils or its prevention does not appear to be associated with toxicity. These results are consistent with reports by others that A β oligomers are more toxic than A β fibrils, and

that a variety of sub-fibril sized species are toxic (1-5). The inability of Hsp20 to prevent A β fibril formation under the conditions used may be due to temperature affects on Hsp20 oligomerization. At 4° C., there may be insufficient active Hsp20 dimers present to prevent fibril formation or hsp20 may be subject to cold denaturation and inactivation at 4° C. (data not shown). Alternatively, the energetics of the Hsp20-A β interaction may be adversely affected by the drop in temperature. In addition, under slow aggregation conditions, the relative abundance of the A β species that bind to Hsp20 may be significantly different than under rapid aggregation conditions under which the Hsp20 optimum concentration was determined.

A number of different approaches have been explored for prevention of A β amyloid fibril formation and toxicity. Pentapeptides such as SEQ ID NO.: 6 KLVFF (8), SEQ ID NO.: 7 LPFFD (30), SEQ ID NO.: 8 GVVIN, SEQ ID NO.: 9 RVVIA (31) have been used to disrupt A β fibril formation and neurotoxicity. These pentapeptides have the same or similar residues as segments of A β essential for fibril formation, bind to A β , and alter the structure that A β adopts (30). Generally, 1 to 1 molar ratios of peptide inhibitors to A β are needed in order to effectively prevent fibril formation (8). Amphipathic molecules such as hexadecyl-N-methylpiperidinium (HMP) bromide or sulfonated molecules such as Congo Red have also been used to prevent A β fibril formation and toxicity.

FIG. 8 is a nucleic acid sequence of an Hsp20 for use with the present invention (SEQ ID NO.:1).

FIG. 9 is the amino acid sequence of an Hsp20 (SEQ ID NO.: 2) for use with the present invention in accordance with SEQ ID NO.: 1.

FIG. 10 is a predicted secondary structure for Hsp20, which predicts that Hsp20 is likely to contain a large amount of beta sheet secondary structure. CD measurements were carried out to determine if these structures are present in the Hsp20 studies herein. Based on the predicted structure, sub-fragments of hsp20 may be produced to determine if they may have the same activity as the whole protein. For example, it has been determined that the Hsp20 active form is likely to be a dimer. As such, deletion scan may be conducted in which a small number of residues, e.g., beginning with the N-terminal 5-10 amino acid, to determine if the Hsp20 is able to form dimers. Dimers may be detected using, e.g., physical observation (antibody capture assays, magnetic bead binding, electron microscopy using gold beads of different sizes) or read out assays, e.g., fluorescence resonance electron transfer (FRET), surface plasmon resonance effects, yeast two hybrid, etc. In fact, some inactive or partially active forms of the monomer and/or dimer are also useful as controls and the like. For example, if the larger inactive complexes are not allowed to form, the hsp20 will be active over a much wider concentration range. Studies conducted to date (data not shown), for example, indicate that the intermediate forms of amyloid are the likely target for binding of hsp20. It appears to be a 10-mer in the first set of studies.

Circular Dichroism Measurements. FIG. 11 is a graph of CD measurements carried out on an AVIV model 62. The wavelength scan was performed at various temperatures from 250 to 200 nm reading every 0.5 nm and averaging each reading for 5 seconds. Circular Dichroism revealed a high beta sheet secondary structure, typical of α -crystallin domains. In vivo studies have revealed properties unique to this α -crystallin.

As described hereinabove, the heat shock protein, Hsp20 from *B. bovis* prevents A β aggregation and toxicity at very low concentrations of small heat shock protein relative to A β (1:1000). A series of studies were conducted to examine the

mechanism of Hsp20 activity and compare it to activity of other small heat shock proteins. The aggregation and toxicity prevention properties of two other small heat shock proteins, Hsp17.7 from carrot, and human recombinant Hsp27 were examined. Both sHsps inhibited A β 1-40 aggregation but not toxicity. Electron microscope images of Hsp-A β complexes that formed under conditions and where both aggregation and toxicity prevention were observed were compared to Hsp-A β complexes that formed when only aggregation prevention was seen (data not shown). In cases where both aggregation and toxicity prevention were seen, a large ring structure was observed repeatedly, which was absent when aggregation was prevented, but toxicity was not prevented. For discussion, but by no means a limitation to this invention, it may be postulated the Hsp20-A β interaction leads to both toxicity and aggregation prevention. The present invention provides constructs, vectors, proteins, methods and the like for preventing protein aggregation and toxicity of A β as well as detailed instructions for designing the next generation of A β aggregation inhibitors to be used in AD.

β -Amyloid (A β 1-40) was purchased from AnaSpec (San Jose, Calif.) and Biosource International (Camarillo, Calif.). Recombinant human Heat Shock Protein 27 (Hsp27) was purchased from MBL International Corporation (Woburn, Mass.). Human neuroblastoma SH-SY5Y cells (ATCC number: CRL-2266) were purchased from ATCC (Manassas, Va.). Cell culture reagents were purchased from Invitrogen Life Technologies (Carlsbad, Calif.). Congo red was purchased from Fisher Chemicals. (Pittsburgh, Pa.). All other chemicals, unless otherwise specified were obtained from Sigma-Aldrich Co.

Heat Shock Protein 20 (Hsp20) Preparation Hsp2.0. was isolated from *Babesia bovis*, [12] and Hsp20 with the N-terminal polyhistidine fusion protein was produced in recombinant *E. coli*. Hsp20 was prepared by growing cells to OD₆₀₀ of 0.5 followed by induction with 1 mM IPTG for 5 hours, and removal of media. The cells were then lysed in PBS using a French pressure cell and the insoluble His-Hsp20 pellet collected. The pellet containing His-Hsp20 was suspended in Denaturing Binding Buffer (Invitrogen) containing 8M urea and incubated with Probond resin for 1 hour to allow binding of His-Hsp20 to the nickel chromatography resin. The protein was eluted from the resin using 100 mM EDTA, dialyzed overnight into PBS pH 7.0, 20% glycerol and frozen at -80° C. Protein purity and molecular weight were confirmed by SDS PAGE.

Heat Shock Protein 17.7 (Hsp17.7) Preparation. The gene, encoding Hsp17.7 from carrot, was cloned in *E. coli* (M. K. Malik, J. P. Slovin, C. H. Hwang, and J. L. Zimmerman, Modified expression of a carrot small heat shock protein gene, hsp17.7, results in increased or decreased thermotolerancedouble dagger, Plant J. 20 (1999) 89-99). *E. coli* was grown in the LB media (Tryptone (10 g/L), Yeast Extract (5 g/L) and NaCl (10 g/L)) with 50 μ g/ml kanamycin broth on the wheel for aeration overnight. The tubes of LB broth were inoculated at a 1:200 dilution and put on wheel at 37° C. 100 mM IPTG was added to cells in order to induce Hsp17.7 when *E. coli* reached an OD₆₀₀ of 0.6. *E. coli* was put back on the wheel and Hsp17.7 was expressed at 37° C. overnight. The cells were harvested by centrifugation at 6,000 rpm for 10 minutes and frozen at -20° C. overnight. The cells were lysed with 20 mM imidazole and 10 min sonication. Hsp17.7 was purified by using a metal affinity column (POROS® MC) (Framingham, Mass.) with copper chromatography resin. (Self Pack™ POROS® 20MC Media) (Framingham, Mass.) The protein was eluted by pH gradient from pH 7.4 (Phosphate buffer, 50 mM NaH₂PO₄, and 300 mM NaCl) to pH 4.5

(Phosphate buffer). Protein purity and molecular weight were confirmed by size exclusion chromatography.

Protein Sample Preparation. A β 1-40 was dissolved in 0.1% (v/v) Trifluoroacetic acid (TFA) solvent at the concentration of 10 mg/ml. This solution was incubated at room temperature for 20–30 minutes in order to completely dissolve the A β . Filtered phosphate-buffered saline (PBS, 4.3 mM Na₂HPO₄, 137 mM NaCl, 2.7 mM KCl and 1.4 mM KH₂PO₄, pH 7.4) was added to the A β solution to make the final concentrations used in experiments. For cell viability assays, MEM medium was used instead of PBS buffer. A β samples were mixed on the rotator at 18 rpm and 37° C., and samples were taken out as a function of time. sHsps were added to the A β samples before the samples were incubated (prior to aggregation).

Congo Red Binding. Congo red was dissolved in PBS at the concentration of 120 μ M and syringe filtered. The Congo red solution was mixed with protein samples at 1:9 (v/v) ratios to make the final concentration of Congo red 12 μ M. After a short vortex, the mixtures were incubated at room temperature for 30–40 minutes. Absorbance measurements from 400 nm to 700 nm were taken (UV-Vis spectrometer model UV2101, Shimadzu Corp.; Kyoto, Japan). Alternatively, Congo red absorbance was read at 405 nm and 540 nm using an Emax Microplate Reader (Molecular Devices, Sunnyvale, Calif.). In both cases, PBS buffer was used as a blank. The concentration of A β fibrils was estimated from Congo red binding via equation (1):

$$[A\beta_{FIB}] = (541 A_t / 4780) - (403 A_t / 6830) - (403 A_{CR} / 8620) \quad (1)$$

where $541 A_t$ and $403 A_t$ are the absorbances of the Congo red-A β mixtures at 541 nm and 403 nm, respectively, and $403 A_{CR}$ is the absorbance of Congo red alone in phosphate buffer. [27] In Microplate reader, absorbances at 405 nm and 540 nm were assumed to be same as those at 403 nm and 541 nm.

A β Turbidity Assay. Protein samples (100 μ M A β and 100 μ M A β +sHsps) were prepared as described in Protein Sample Preparation. At every 30 minutes until 8 hours, turbidity of protein samples was monitored at 405 nm using UV-Vis spectrometer (model UV2101, Shimadzu Corp.; Kyoto, Japan). PBS buffer solution was used as a blank.

Electron Micrograph (EM). 200 μ l of A β peptide solution, prepared as described above, was mixed, placed on glow discharged grids, and then negatively stained with 1% aqueous ammonium molybdate (pH 7.0). Grids were examined in a Zeiss 10C transmission electron microscope at an accelerating voltage of 80 kV. Calibration of magnification was done with a 2,160 lines/mm crossed line grating replica (Electron Microscopy Sciences, Fort Washington, Pa.).

Cell Culture. SH-SY5Y cells were grown in Minimum Essential Medium (MEM) supplemented with 10% (v/v) Fetal Bovine Serum (FBS), 25 mM Sodium bicarbonate, 100 units/ml penicillin, and 100 mg/ml streptomycin. Cells were cultured in a 5% (v/v) CO₂ environment at 37° C. incubator. Low passage number cells were used (<p20) in all experiments to reduce instability of cell line.

Biological Activity Assay. For biological activity tests, SH-SY5Y cells at a density of 1×10^6 cells/mL were grown in 96 well plates. Cells were fully differentiated by addition of 20 ng/mL NGF for 8 days. A β samples in MEM medium were added to the differentiated SH-SY5Y cells and the cells were incubated with A β samples at 37° C. for 2 hours. Negative controls (cells in medium with no A β) and positive controls (cells treated with 800 μ M H₂O₂ in 50% (v/v) medium for 2 hours) were also prepared. At least 3 wells were prepared for each A β treatment, and each positive and negative control.

Cell viability was determined by using the fluorescent nucleic acid dye, propidium iodide (PI). PI is mostly used fluorescent dye for staining DNA in cells. PI can enter the dead cells and bind DNA in dead or late apoptotic cells. PI is a DNA specific dye and can not cross the membrane of viable cells. In order to stain the dead cells, A β treated cells were washed with PBS 1–2 times and 150 μ L of enzyme free dissociation buffer from Gibco (Carlsbad, Calif.) was added to the cells in order to detach SH-SY5Y cells from the surface. The cells were incubated at 37° C. for approximately 5 minutes. 5 μ L of 33 μ M PI was added to the cells and cells were incubated for 1520 minutes at room temperature in the dark. Stained cells in 96 well plates were loaded in the FACS array (BD FACSArray, BD Bioscience; San Jose, Calif.) and fluorescence histograms for cells were obtained. To set up gates for the cell viability assays, 2 sets of staining controls were prepared, unstained cells, and cells stained with PI alone. Cells not stained with PI dye were taken as live cells, and the relative cell viabilities were calculated using equation (2).

$$\text{Relative Cell Viability (\%)} = \frac{(L.C._{sample} - L.C._{H2O2})}{(L.C._{Ncontrol} - L.C._{H2O2})} \times 100 \quad (2)$$

where $L.C._{sample}$ is live cells (%) of cells treated with A β and sHsps, $L.C._{Ncontrol}$ is live cells (%) of negative control, and $L.C._{A\beta}$ is live cells (%) of cells treated with only A β .

Statistical Analysis. For each study, at least 3 independent determinations were made. Significance of results was determined via the student t test with $p < 0.05$ unless otherwise indicated. Data are plotted as the mean plus or minus the standard error of the measurement.

Effect of Hsp20 on A β Aggregation and Toxicity. A β is toxic to neuron-type of cells when in aggregated form. Results to date indicated that His-Hsp20 has been very promising as an A β aggregation and toxicity inhibitor (S. Lee, K. Carson, A. Rice-Ficht, and T. Good, Hsp20, a novel alpha-crystallin, prevents A-beta fibril formation and toxicity, Protein Sci. 14 (2005) 593-601). Congo red binding was used as an indicator of extended β -sheet structure and changes in A β aggregation in this research. As shown in FIG. 12A, His-Hsp20 prevents A β aggregation, showing the characteristic U-shape pattern. At lower His-Hsp20 concentrations than 0.1 μ M, A β fibril formation decreases as a function of His-Hsp20 concentration. However, His-Hsp20 becomes less effective at preventing A β fibril formation in the higher concentrations. In FIG. 12A, we also show the effect of His-Hsp20 on A β toxicity. His-Hsp20 prevents A β toxicity over wide range of concentrations. SH-SY5Y cells treated with the Hsp20-A β mixture shows higher cell viabilities (61.3% \pm 2.6%–78.0% \pm 3.6%) than those treated with 100 μ M A β (45.3% \pm 1.7%). Statistically, cell viabilities of A β itself are different from all cell viabilities of Hsp20-A β mixtures. (all p values between A β and Hsp20-A β mixture are less than 0.05)

Effect of Hsp17.7 on A β Aggregation and Toxicity. As shown in FIG. 12B, Congo red result shows that His-Hsp17.7, a small heat shock protein derived from carrot, prevents A β aggregation at all concentrations between 1 nM and 20 μ M, without the apparent loss of activity at even higher concentrations (up to 20 μ M). As for toxicities in FIG. 12B, addition of 20 μ M A β to SH-SY4Y cells results in about 30% toxicity. Hsp17.7-A β mixtures have almost same toxicities like A β alone. Statistically the toxicities between Hsp17.7-A β mixture and A β alone are not different. (all p values are greater than 0.05 between A β sample and other samples containing

Hsp17.7). Thus, unlike Hsp20, Hsp17.7 prevents A β aggregation without preventing A β toxicity.

Effect of Hsp27 on A β Aggregation and Toxicity. FIG. 12C shows the biological activity of A β when incubated with Hsp27 with near the same effectiveness and at similar concentration ranges as Hsp17.7. Unlike Hsp20, Hsp27 doesn't lose its ability to prevent A β aggregation at high concentrations (5 μ M of Hsp27). In the toxicity experiments shown in FIG. 12C, the samples containing Hsp27 incubated with A β have the same or more toxicity than the toxicity of A β alone. Statistically, cell viabilities of 100 μ M A β with 5 nM-1 μ M Hsp27 are not different from that of 100 μ M A β . (all p values are greater than 0.05) 1 nM and 5 μ M Hsp27 increases the toxicity of 100 μ M A β . In other words, Hsp27 doesn't protect the cells from the A β toxicity.

Kinetics of sHsps-A β Interaction (Congo red and Turbidity). For Hsp20 to be a useful aggregation inhibitor (or model for an aggregation inhibitor) for A β , it is important to discern if Hsp20 simply slows the rate of aggregation of A β , or actually alters the aggregation pathway of A β . To that end, kinetics of A β aggregation were measured as assessed via Congo red binding and turbidity in the presence and absence of sHsps. As seen in FIG. 13, A β aggregation increases slowly at first, followed by a period of rapid increase in fibril content, which eventually saturates over time. When Hsp20 is added at the beginning of aggregation, fibril formation and Congo red binding follow a very different pattern. Initially, aggregation is accelerated, followed by a rapid loss in fibril content and ability to bind Congo red. These results suggest that Hsp20 does not simply slow the rate of A β aggregation, but actually changes the fibril formation pathway, possibly sequestering a fibril initiating species that forms early during aggregation and preventing further fibril growth. Hsp17.7 and Hsp27 also change the fibril formation pathway. However, both Hsp17.7 and Hsp27 don't show accelerated aggregation in the early incubation time like Hsp20. Turbidity assay in FIG. 14 shows more drastic differences between Hsp20 and other sHsps. A β fibril formation follows a characteristic sigmoidal curve, with a lag phase at early incubation times, followed by a fibril growth phase, then a saturation phase. A β initially mixed with Hsp20 shows higher intensities at earlier incubation time between 0 and 4 hours, which means Hsp20-A β mixture forms big species. In Congo red result, Hsp20-A β mixture at 2 hours shows more Congo red binding than other samples. Both results suggest that Hsp20-A β mixture forms big size species with β -pleated sheet at earlier incubation time. Hsp27-A β mixture shows higher intensity at 1 hour, which doesn't make big differences after that. Hsp17.7-A β mixture doesn't show higher intensity at earlier incubation time.

Ability of His-Hsp20 To Prevent Toxicity of A β with Time. In order to assess the ability of His-Hsp20 to prevent A β toxicity, His-Hsp20 was added to A β samples prior to A β aggregation, and toxicity of the Hsp20-A β mixtures were tested as a function of time after incubation. As seen in FIG. 14, His-Hsp20 prevents A β toxicity. Statistically, cell viabilities of Hsp20-A β mixture at 2, 4, and 8 hours are not different from negative control (p=0.862, 0.087, and 0.140 for 2, 4, and 8 hours respectively, all p values are greater than 0.05), which means His-Hsp20 protects the cells from A β toxicity completely. At 2, 4, and 8 hours, A β shows only 50-70% cell viability compared to negative control. At 24 hours, Hsp20-A β mixtures have cell viability of about 80%, whereas A β shows only about 40% cell viability. Although His-Hsp20 doesn't prevent A β toxicity completely at 24 hours, His-Hsp20 still reduces the A β toxicity (viability is statistically different between A β and Hsp20-A β mixture).

Electron Micrograph (EM) Images of A β with Small Heat Shock Proteins. To further exam the relationship between A β structure, sHsp-A β interactions, and aggregation and toxicity prevention activities, electron microscopy was used to examine structures formed by A β in the presence of the small heat shock proteins. In one set of studies, structures formed by 100 μ M A β and 0.1 μ M His-Hsp20 were examined as a function of time during incubation with mixing, analogous to the kinetic data shown in FIG. 13. As early as 1-hour after incubation, A β and Hsp20 begin to complex ring-like structures. (data not shown)

As seen in FIG. 15, a better defined multi-ring structure is observed at two hours. The appearance of this large multi-ring structure corresponds to the maximum in Congo red binding seen in Hsp20-A β mixtures seen in FIG. 13. At later times, the ring structures seem to fall apart, with few rings observed in micrographs at 24 hours after incubation. (data not shown). The large multi-ring structure is only seen in micrographs of A β and Hsp20 when 100 μ M A β and 0.1 μ M Hsp20 are used. When the same concentration of A β , but higher and lower concentrations of Hsp20 are used (1 nM, 0.01 μ M, 1 μ M, and 5 μ M Hsp20), the complex ring structure is not observed (data not shown). As seen in FIG. 16, similar electron microscopy studies were performed with A β and Hsp17.7. At no time during incubation of A β and Hsp17.7 are the large multi-ring complexes observed in micrographs. Also examined were structures formed 24 hours after incubation of A β and Hsp17.7, as these structures would represent the complexes added to cells in culture for toxicity assays. Some isolated fibrils from Hsp17.7-A β mixture are observed at 24 hours (data not shown), which is very different from Hsp20-A β mixture at 24 hours. Differences in these structures might point to clues as to the differences in structures formed and their relationship to cell toxicity.

In Alzheimer's disease (AD) and in dementia associated with Parkinson's disease, an increased expression of Hsp27 and of α β B-crystallin was found (T. Iwaki, A. Kume-Iwaki, R. K. Liem, and J. E. Goldman, Alpha B-crystallin is expressed in non-lenticular tissues and accumulates in Alexander's disease brain, *Cell* 57 (1989) 71-78; K. Renkawek, G. J. Stege, and G. J. Bosman, Dementia, gliosis and expression of the small heat shock proteins hsp27 and alpha B-crystallin in Parkinson's disease, *Neuroreport* 10 (1999) 2273-2276). These results suggest that chaperone activity of heat shock proteins may contribute to the pathogenesis associated with protein aggregation in Alzheimer's disease (Y. C. Kudva, H. J. Hiddinga, P. C. Butler, C. S. Mueske, and N. L. Eberhardt, Small heat shock proteins inhibit in vitro A beta(1-42) amyloidogenesis, *FEBS Lett.* 416 (1997) 117-121).

Small heat shock proteins (sHsps) are expressed in almost all organisms when cells become stressed during exposure to unfavorable environments. Small heat shock proteins exist as large oligomeric complexes of 300-800 kDa with monomeric molecular mass of 15-43 kDa (J. I. Clark, and P. J. Muchowski, Small heat-shock proteins and their potential role in human disease, *Curr. Opin. Struct. Biol.* 10 (2000) 52-59; T. H. MacRae, Structure and function of small heat shock/alpha-crystallin proteins: established concepts and emerging ideas, *Cell Mol. Life Sci.* 57 (2000) 899-913; I. P. van den, D. G. Norman, and R. A. Quinlan, Molecular chaperones: small heat shock proteins in the limelight, *Curr. Biol.* 9 (1999) R103-105). The primary roles of sHsps are to stabilize other proteins under stress conditions and protect them from aggregation (J. M. Bruey, C. Ducasse, P. Bonniaud, L. Ravagnan, S. A. Susin, C. Diaz-Latoud, S. Gurbuxani, A. P. Arrigo, G. Kroemer, E. Solary, and C. Garrido, Hsp27 negatively regulates cell death by interacting with cytochrome c,

Nat. Cell. Biol. 2 (2000) 645-652). sHsps are composed of three parts in the primary sequence, the N-terminal domain, the α -crystallin domain, and the C-terminal extension. The α -crystallin domains, highly conserved 80-100 amino acid sequences located in the C-terminal regions, are very important for substrate binding. [34] Other research groups showed that α B-crystallin prevented A β fibril formation in vitro, but not the toxicity (G. J. Stege, K. Renkawek, P. S. Overkamp, P. Verschuure, A. F. van Rijk, A. Reijnen-Aalbers, W. C. Boelens, G. J. Bosman, and W. W. de Jong, The molecular chaperone α B-crystallin enhances amyloid beta neurotoxicity, Biochem. Biophys. Res. Commun. 262 (1999) 152-156). Human Hsp27 inhibited fibril formation of A β 1-42 in vitro, but it was less effective on the pre-formed amyloid.

In FIG. 12A, Hsp20 prevented A β aggregation over 80% in the Hsp20 concentration of 1 nM-1 μ M, and also reduced A β toxicity in this ranges. FIGS. 12B and 12C show that both Hsp17.7 and Hsp27 prevent A β aggregation but not toxicity. Therefore, it was found that Hsp17.7 and Hsp27 prevents only A β 1-40 aggregation, whereas Hsp20 prevents A β 1-40 aggregation and toxicity. The α -crystallin domains of these sHsps could be the crucial parts of the proteins in preventing A β aggregation because the α -crystallin domains are well-conserved regions and are found in Hsp20, Hsp17.7, and Hsp27. The results of sequence homologies using the software CLUSTALW (EMBL-European Bioinformatics Institute) show that the sHsps lack sequence homology in both the N-terminus, and C-terminal extension. (32%- α B-crystallin and Hsp27, 15%- α B-crystallin and Hsp17.7, 8%- α B-crystallin and Hsp20, 17%-Hsp20 and Hsp17.7, 7%-Hsp20 and Hsp27, and 7%-Hsp17.7 and Hsp27). These differences could result in different binding affinity between sHsp and A β or in different mechanisms by which when they prevent A β aggregation. In FIG. 13 and FIG. 14, sHsps-A β mixtures don't change the Congo red and turbidity with time in the saturation phase, which are parallel to A β . It suggests that all sHsps prevent A β aggregation by changing A β aggregation pathways rather than slowing down A β aggregation. In FIG. 13 and FIG. 14, Hsp20 shows very different pattern to prevent A β aggregation from other sHsps. One of the possible explanations is that Hsp20 has stronger binding affinity with A β than other sHsps. Different binding affinity results in Hsp20 binding to A β in earlier stage of A β aggregation which are not toxic species to the cells, whereas other sHsp bind to A β in later stage of A β aggregation. As a result, Hsp20 prevents A β aggregation more than other sHsp in FIG. 12A, 12B and FIG. 12C.

Apparently, the large multi-ring formation of Hsp20 with A β seems to be related to the ability of Hsp20 to prevent both A β aggregation and toxicity. FIGS. 13, 14 and 15 indicate that only Hsp20 forms a large multi-ring structure with A β (at 2 hours in mixing condition), whereas the other sHsps were not observed to form ring structures. The stoichiometric binding between Hsp20 and A β could be associated with the large multi-ring formation and optimum activity of Hsp20 in prevention of A β aggregation. In order to know the effect of Hsp20 assembly on A β aggregation, a novel Hsp20 construct was prepared that was missing 11 residues from the C-terminus that are partly responsible for Hsp20 assembly. This form of Hsp20 forms stable dimers under most conditions. The activities of the non-aggregating form of Hsp20 and the aggregating Hsp20 were compared, and find little difference in their aggregation prevention and toxicity behaviors (data not shown). These results suggest that the binding ratio (stoichiometric binding) between Hsp20 (dimer) and A β is more important in A β aggregation prevention than Hsp20 assembly. Other sHsps could follow different mechanism via

assembly from Hsp20. First, sHsps could assemble to form oligomeric complexes such as hollow cylindrical or spherical structure, and then sHsp assemblies protect the hydrophobic parts of A β from aggregation.

These results demonstrate that Hsp20 may have a unique mechanism of interaction with A β that results in different activity in A β toxicity prevention relative to other sHsps. FIG. 14 shows that Hsp20-A β mixture has the same cell viabilities as negative control until 8 hours, although Hsp20 doesn't protect the cells completely from A β toxicity at 24 hours. Again, Hsp20 can delay A β toxicity via a unique mechanism of interaction with A β . In Alzheimer's disease, even delaying A β aggregation onset or slowing its progression might be therapeutically useful, as disease onset is late in life.

The kinetics of amyloid formation changes in the presence of hsp20. It is not simply a slowing of the process but the use of a different pathway.

FIG. 18 shows the dynamic relationship of hte oligomeric states of hsp20 using FPLC analysis of 29 μ M hsp 20 in 500 mM NaCl (13.69=16mer; 15.05=10mer; 16.85=hexamer; 17.99=tetramer; 20.18=dimer; 22.72=monomer Dimer=15% of total).

Kinetics of Hsp20 fibril prevention activity. Next, it was determined whether Hsp20 simply slowed the rate of aggregation of A β or if it altered the aggregation pathway such that non toxic species were formed. This was an important question, as if Hsp20 simply slowed the rate of aggregation, then it would be a much less attractive aggregation inhibitor than if it actually changed the aggregation pathway away from toxic species. As can be seen from FIG. 17, in physiological buffers, A β aggregates until approximately 40% of the peptide is incorporated into fibrils by 10 hours, after which time no further increase in Congo red binding is observed. However, in the presence of Hsp20, maximum Congo red binding occurs within 4 hours, after which a loss in Congo red binding is observed. Similar trends were observed in toxicity studies as a function of time with analogously prepared samples. These data suggest that Hsp20 does not simply slow down A β aggregation, but alters the A β aggregation pathway. A turbidity assay also reveals the same results.

Hsp20 exists in multimeric forms. The existence of the forms is concentration dependent. Only the lowest concentrations with smaller oligomeric forms are active in blocking A β fibril formation.

Self-assembly of hsp20 into multimeric complexes. Among α -crystallins that have been well studied, a variety of oligomeric states have been observed and correlated with active and inactive states of the proteins. An analysis of the dynamic relationship of the oligomeric states of hsp20 and their relationship to α -crystallin activity was conducted. One approach that has been successful with the His-tagged protein, and which was largely unsuccessful with the larger MBP fused version is analysis of hsp20 at several concentrations through FPLC. Superose 6 resin (Pharmacia) and size exclusion standards have been used to create a standard curve of elution volume versus standard molecular weight. When purified recombinant his-Hsp20 is applied to the column at intermediate concentrations under high salt conditions, (29 μ M) a number of discrete oligomeric states are observed (FIG. 19). Elution volumes correspond to the following multimeric species: 13.69=16mer; 15.05=10mer; 16.85=6mer; 17.99=tetramer; 20.18=dimer; 22.72=monomer. The dimeric form of the protein constitutes approximately 15% of the total hsp20 applied to the column.

At intermediate concentrations (29 μ M, FIG. 19) the dimeric species constitutes approximately 42% of the protein eluted from the column. When this same protein solution is

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diluted further to a final concentration of 0.1 μ M, and applied to size exclusion chromatography, the dimer is the predominant species, constituting more than 95% of the eluted protein (not shown), suggestions that an equilibrium exists between species, and that the dimeric form of the protein may be produced selectively by designing experiments at low concentrations of Hsp20. Alternatively, the production of a dimeric species stable at higher concentrations would be advantageous.

In an effort to find the smallest active piece of hsp20 with respect to prevention of ADH denaturation and A β fibril formation, hsp20 was truncated at C the and N terminus. All truncated forms prevent ADH denaturation. C-terminal truncation and full length prevent A β fibril formation. The other truncated versions (N-terminal and N and C terminal) may also be tested in the fibril assay. The truncated forms were made to stabilize hsp20 in the form which is most active:

Stabilization of specific complexes; alteration of the steady state level of specific species. Based on the X-ray crystallographic analysis of other alpha crystallins the putative hsp20 domains governing assembly of dimers, dodecamers and larger ordered alpha crystalline structures were identified. Using recombinant DNA technology truncations of specific regions of the hsp20 recombinant protein were constructed and tested to show: (1) the equilibrium distribution of oligomer of the truncated protein, (2) activity in an ADH denaturation assay of the truncated protein and, (3) amyloid fibril prevention by the altered protein.

FIG. 20 is a sequence alignment of M.j-sHSP and *B. bovis* HSP20; N terminal and C terminal deletions with the C-terminal deletion of HSP20=EMRRVQIDAKA (SEQ ID NO.: 5).

Based on the analysis of an alpha crystalline derived from a thermophilic bacteria by Laksanalamai, et al (2003), the carboxy-terminal 12 amino acids of hsp20 were removed (FIG. 20) in order to reduce or eliminate the assembly of dimers into dodecamers, thus trapping hsp20 in dimer configuration. When the recombinant protein was applied to FPLC (Superose 6 resin), approximately 42% of the preparation migrated as a dimeric species on the column (FIG. 21). These results are in contrast to the full length hsp20 which at equilibrium demonstrates only 1-2% dimer at similar concentrations (Lee, et al., 2005). The carboxy-terminal truncated protein preparation, highly enriched for dimeric species was tested in an ADH assay (FIG. 22) and found to be equivalent in activity to the native protein in that it prevented thermal denaturation of ADH at identical molar ratios (1:2 and 2:1, hsp20:A β). When tested in an A β assay to prevent fibril formation, a preliminary study showed its activity to also be similar to that of the native preparation (FIG. 21). Further constructs have been made that lack the N terminal 50 amino acids and would be predicted to form dodecamers but lack the ability to form higher order complexes. A third protein lacks both the C-terminal 12 amino acids as well as the N-terminal 50 amino acids. The truncated proteins, which have an intact alpha crystalline domain, are virtually identical in its ability to block ADH denaturation (FIG. 22).

A honeycomb pattern of A β -hsp20 complex is detected in EM when ever anti-fibril activity is present (see FIG. 17). After approximately 2 hours of incubating A β peptide in the presence of hsp20, an increase in turbidity is seen. This turbidity has proved transient as it then decreases over time. An EM of that 2 hour time point reveals an interesting "honeycomb" pattern which the inventors believe is an A β -hsp20 complex. It is not known at this time what the significance of this complex is, however, it may lead to an alternate interaction pathway for A β that does not lead to amyloid formation.

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FIG. 23 is a graph that shows that fibril formation of A β peptide in the presence of full length and truncated hsp20.

The present invention includes a novel small heat shock protein with demonstrable A β fibril formation and toxicity prevention activity. Biophysical characterization was performed on the small heat shock protein to determine that it is most likely active as a small oligomer or dimer, which is formed most readily at low concentrations or elevated temperatures. The small heat shock protein disclosed herein prevented both fibril formation and toxicity at very low mole ratios of heat shock protein to A β , suggesting that a low abundance A β aggregation intermediate interacts with the small heat shock protein. These results show that the small heat shock protein alters the aggregation pathway as opposed to simply altering the rate of aggregation. In addition, stable complexes of A β and the small heat shock protein were isolated, which may be used for A β aggregation/toxicity prevention.

FIG. 24 shows the amino acid sequences for the full length, amino terminal truncated, carboxy terminal truncated, both the amino and carboxy terminal truncated, a his-tagged full length, a his-tagged amino terminal truncated, a his-tagged carboxy terminal truncated, and a his-tagged the amino and carboxy terminal truncated proteins that were developed for and are part of the present invention.

Table 1. Coding sequence of *B. bigemina* Hsp 20. The his-tagged is highly related to the *B. bovis* Hsp20. The full-length his-tagged version shows the same protection of ADH aggregation at 58 deg. C. (same method as that used for *B. bovis* HSP20).

Extra amino acids in the His-HSP20 clone met-gly-gly-ser-his(6)-gly-met-ala-ser-met-thr-gly-gly-gln-gln-met-gly-arg-asp-leu-TYR-asp(4)-lys-asp-pro-thr-leu-glu-asn-leu-tyr-phe-gln-gly-

(SEQ ID NO: 10)
(MGGSHHHHHGMSMTGGQQMGRDLYDDDDKDPTEENLYFQG)

after cleavage, only gly remains.

Entire Coding sequence (including purification tag and TEV protease site):

(SEQ ID NO: 11)
MGGSHHHHHHHGMSMTGGQQMGRDLYDDDDKDPTEENLYFQGMSCIMRCN
NSEQEVDVIDEQTGLPVKNHDYTEKPSVIYKPSITVPQNTILEIPPPKELE
TPITFNPTVDTFFDADTNKIVVLMELPGFSHNDITVECGLGELIISGRPP
KDELYEKFNNLDIHIRERKVGIFYRRFKLPHNALDKSVAVSYNSGILDI
RIECSQFSEMRRIQIDGKA

NA coding sequence of above protein sequence:

(SEQ ID NO: 12)
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TGGACAGCAAATGGGTCGGGACTGTACGACGATGACGATAAGGATCCAA
CCCTTGAAAATCTTTATTTCAAGGTATGTCGTGCATTATGAGGTGCAAC
AACTCCGAACAGGAGGTGTGCATCGATGAGCAGACGGGACTCCAGTGAA
GAACACGACTACACTGAGAAGCCCTCTGTGATTACAAAGCGTCGACCA
TTGTTCTCTAAAACACCATCCTTGAGATCCCTCTCCCAAGGAAGTGGAA
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-continued

CAACAAGATCGTTGTTTGGATGGAAGTGCCTGGATTGAGCCACAACGACA
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 AAGGACGAGCTTTACGAGAAGTTCCGGTAACAACCTTGACATCCACATCCG
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 CCTTGGACAAGTCTGTTGCTGTGTCTTACTCCAACGGTATCTTGGACATC
 AGGATTGAGTGCTCGCAGTTCTCCGAGATGCGCCGATCCAGATCGACGG
 CAAGGCATAA

In FIG. 26, the multimeric state of HSP20 (full-length and various deletions) is analyzed by crosslinking. The cross-linked samples are then visualized via electrophoresis on a denaturing 12% polyacrylamide-SDS gel. Briefly, the reaction is carried out in cross-linking buffer (1 mM DTT, 100 mM NaCl, 0.2 mM EDTA, 0.05% v/v NP40, 10% v/v glycerol, 25 mM HEPES, pH 8.0) and the diluted purified protein samples are mixed at a ratio of 1:1 with Cross-linking Buffer. Next, 3 μ l of 0.1% glutaraldehyde are added to 27 μ l of protein. At 5, 10 and 20 minutes, 10 μ l aliquots are withdrawn and combined with 10 μ l of tris-glycine buffer (to quench the cross-linker). For loading on SDS-PAGE, an equal volume of 2 \times SDS loading dye is added and the samples are boiled for 5 minutes and ran on 12% SDS PAGE.

In the figures, high-order structures are seen forming at the top of the gel within 5 minutes. The monomeric protein is depleted over time indicating its role in multimer formation. These figures demonstrate that the full-length forms high-order oligomers. Also, the C-terminal deletion (12 aa), N-terminal deletion (50 aa) and N-C-terminal double deletion (62 aa) seem to still form very high order oligomers despite the fact that $\frac{1}{3}$ of the 177-residue protein has been removed. This observation along with the fact that the C-terminal deletion has no affect on its amyloid protection activity or ADH aggregation protection by the N-, C- and N-C-terminal deletions suggest that a much smaller region of the protein is responsible for the activities observed (specifically aggregation and amyloid protection).

FIG. 25 is a gel that shows the effect of the truncations (as listed) on the target protein, and that the monomeric protein is depleted over time indicating its role in multimer formation. FIG. 26 is a gel that shows the effect of the truncations (as listed) on the target protein, and that the monomeric protein is depleted over time indicating its role in multimer formation.

It will be understood that particular embodiments described herein are shown by way of illustration and not as limitations of the invention. The principal features of this invention can be employed in various embodiments without departing from the scope of the invention. Those skilled in the art will recognize, or be able to ascertain using no more than routine experimentation, numerous equivalents to the specific procedures described herein. Such equivalents are considered to be within the scope of this invention and are covered by the claims.

All publications and patent applications mentioned in the specification are indicative of the level of skill of those skilled in the art to which this invention pertains. All publications and patent applications are herein incorporated by reference to the same extent as if each individual publication or patent application was specifically and individually indicated to be incorporated by reference.

All of the compositions and/or methods disclosed and claimed herein can be made and executed without undue experimentation in light of the present disclosure. While the

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compositions and methods of this invention have been described in terms of preferred embodiments, it will be apparent to those of skill in the art that variations may be applied to the compositions and/or methods and in the steps or in the sequence of steps of the method described herein without departing from the concept, spirit and scope of the invention. More specifically, it will be apparent that certain agents which are both chemically and physiologically related may be substituted for the agents described herein while the same or similar results would be achieved. All such similar substitutes and modifications apparent to those skilled in the art are deemed to be within the spirit, scope and concept of the invention as defined by the appended claims.

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35      40      45
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65      70      75      80
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What is claimed is:

1. A method of stabilizing a protein with one or more β -pleated sheets comprising providing a protein in, at or about a tissue and in need of stabilization and contacting the protein with a heat shock polypeptide at a molar ratio of the heat shock polypeptide to the protein of between about 0.0005 and 0.001, wherein the heat shock polypeptide comprises SEQ ID NO.: 2 exhibiting α -crystallin activity and inhibiting the formation of A β multimers wherein the protein remains stable and exhibits attenuated neurotoxicity over a one-thousand-fold concentration range.
2. A method of stabilizing a protein with one or more β -pleated sheets comprising contacting the protein with a heat shock polypeptide wherein a molar ratio of the heat shock polypeptide to the protein is between about 0.0005 and 0.001, wherein the protein remains stable over a one-thousand-fold concentration range at 58° C. and the heat shock polypeptide comprises SEQ ID NO.: 2.

3. The method of claim 2, wherein the heat shock polypeptide exhibits α -crystallin activity and inhibits the formation of A β multimers.

4. The method of claim 2, wherein the heat shock polypeptide exhibits α -crystallin activity and attenuates toxicity of A β .

5. A method of attenuating protein aggregation comprising contacting an aggregated protein with a Hsp20, a heat shock polypeptide that comprises SEQ ID NO.: 2 and a molar ratio of the heat shock polypeptide to the protein of between about 0.0005 and 0.001, wherein the protein aggregation is reduced.

6. A method of treating a medical condition that exhibits protein aggregation with one or more β -pleated sheets comprising administering to a subject a heat shock polypeptide wherein a molar ratio of the heat shock polypeptide to the protein is between about 0.0005 and 0.001 whereby the heat shock polypeptide attenuates protein aggregation levels in a neuronal tissue of the subject and wherein the heat shock polypeptide comprises SEQ ID NO.: 2.

7. A method of attenuating protein aggregation with one or more β -pleated sheets comprising contacting an amyloidogenic protein with a heat shock polypeptide wherein a molar ratio of the heat shock polypeptide to the protein is between about 0.0005 and 0.001 and the heat shock polypeptide comprises SEQ ID NO.: 2. 5

8. The method of claim 7, wherein the amyloidogenic protein is in, at or about a tissue.

9. The method of claim 7, wherein the amyloidogenic protein is in, at or about a neural cell. 10

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