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3 **Advanced glycation end products modulate amyloidogenic APP processing and Tau**  
4 **phosphorylation: a mechanistic link between glycation and the development of Alzheimer's disease**  
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**ABSTRACT**

Advanced glycation end products (AGEs) are implicated in the pathology of Alzheimer's disease (AD), as they induce neurodegeneration following interaction with the receptor for AGE (RAGE). This study aimed to establish a mechanistic link between AGE-RAGE signaling and AD pathology. AGE-induced changes in the neuro2a proteome were monitored by SWATH-MS. Western blotting and cell-based reporter assays were used to investigate AGE-RAGE regulated APP processing and tau phosphorylation in primary cortical neurons. Selected protein expression was validated in brain samples affected by AD. AGE-RAGE axis altered proteome included increased expression of Cathepsin B and asparagine endopeptidase (AEP), which mediated increase in  $A\beta_{1-42}$  formation and tau phosphorylation, respectively. Elevated Cathepsin B, AEP, RAGE, and pTau levels were found in human AD brain coincident with enhanced AGEs. This study demonstrates that AGE-RAGE axis regulates  $A\beta_{1-42}$  formation and tau phosphorylation via increased Cathepsin B and AEP, providing a new molecular link between AGEs and AD pathology.

**KEYWORDS:** Advanced glycation end products, Alzheimer's disease, Amyloid beta, Asparagine endopeptidase, Cathepsin B, Diabetes, Proteomics, Tau phosphorylation.

## INTRODUCTION

Alzheimer's disease (AD) is a one of the major causes of dementia in older people leading to cognitive dysfunction.<sup>1</sup> AD is characterized by accumulation of insoluble extracellular senile plaques and intracellular neurofibrillary tangles.<sup>2, 3</sup> The disease affects over 47 million people worldwide and this number is expected to increase to more than 131 million by 2050 as per the World Alzheimer Report 2016. AD is a multifactorial syndrome involving several molecular and cellular processes including inflammation, mitochondrial dysfunction, glycation, protein aggregation, oxidative stress and hyperglycemia.<sup>4-8</sup>

The occurrence of AD is significantly higher in an aging population, as well as in subjects with diabetes, suggesting that dysregulation in glucose metabolism could be one of the causal factors.<sup>9, 10</sup> The peptide hormone insulin has been directly implicated in tau hyperphosphorylation via activation of ERK and GSK3 $\beta$ . Thus hyperinsulinemia is associated with neurofibrillary tangles formation and hence AD progression. In contrast, insulin is also known to promote processing of APP through a non-amyloidogenic pathway, and insulin resistance is associated with increased deposition of A $\beta$  and reduced brain function.<sup>10-13</sup> The inevitable consequence of increased insulin resistance is hyperglycemia leading to protein glycation. Glycation is a non-enzymatic reaction between glucose or other glycolysis intermediates and proteins leading to formation of heterogeneous advanced glycation end products (AGEs).<sup>14</sup> The levels of AGEs increase during biological aging due to decreased efficiency of homeostatic processes.<sup>15</sup> AGEs are associated with AD pathology and are likely involved in the formation of amyloid plaques and neurofibrillary tangles.<sup>7, 16-18</sup> AGEs can induce toxic effects through interactions with the cell surface AGE receptor (RAGE). AD brain shows increased RAGE expression which is involved in the intraneuronal transport of A $\beta$  peptides leading to mitochondrial damage and neuronal dysfunction.<sup>19, 20</sup> Furthermore, glycated A $\beta$  has been shown to exacerbate neuronal damage, through interaction with RAGE, as it acts as a more suitable ligand over unmodified A $\beta$ .<sup>21</sup> Blocking RAGE

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3 signaling with the inhibitor, FPS-ZM1, was found to be effective in reducing A $\beta$ -mediated neuronal  
4 dysfunction in an AD mouse model highlighting the potential importance of AGE-RAGE in AD  
5 pathology and progression.<sup>22</sup> The precise mechanisms involved are not fully defined but RAGE  
6 stimulation leads to activation of NADPH oxidases which induces reactive oxygen species (ROS)  
7 generation. Redox imbalance induces activation of several signal transduction pathways which damage  
8 cells and tissues severely.<sup>23</sup>

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10 Thus, the aim of the current study was to explore the change in the neuronal protein profile in response to  
11 AGE-RAGE signaling and investigate the role of selected regulated proteins in the development of AD  
12 pathology. Human serum albumin (HSA) is the predominant AGE modified protein in plasma, and AD  
13 individuals show increased glycated proteins in Cerebrospinal fluid.<sup>24, 25</sup> Using AGE-HSA as a ligand for  
14 RAGE, we performed label-free quantitative proteomic analysis by SWATH-MS, showing that  
15 AGE/RAGE axis regulates several key proteins implicated in AD including Cathepsin B, asparagines  
16 endopeptidase (AEP), acid ceramidase and CD147. The AGE/RAGE axis stimulated an increase in  
17 Cathepsin B-mediated APP processing, which was associated with increased A $\beta$ <sub>1-42</sub> formation in primary  
18 cortical neurons. AGE/RAGE interaction also led to increased tau phosphorylation. Further, we have  
19 observed increased levels of RAGE, Cathepsin B and AEP correlating with higher levels of AGE  
20 modified proteins and phosphorylated tau in brain homogenates from the temporal cortex of individuals  
21 affected by AD. Hence this study describes a direct association between the AGE/RAGE axis and the  
22 development of AD providing a new mechanistic link between AGEs and dementia.  
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## 44 **RESULTS**

### 45 **Synthesis of AGE-HSA**

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47 AGE-HSA was synthesized by co-incubating glucose and HSA for 90 days under sterile conditions.  
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49 Formation of AGEs was confirmed by measuring AGE-specific fluorescence and western blotting with  
50 anti-carboxymethyllysine (CML) antibody as showed in Figure S2 (Supplementary). Furthermore, AGE-  
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3 HSA was thoroughly characterised for AGE modifications using high resolution accurate mass  
4 spectrometry (Supplementary methods). A list of modified peptides is provided in Supplemental Table  
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### 10 **AGE-HSA induces ROS and apoptosis in neuro2a cells**

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13 AGE-RAGE axis activates NADPH oxidase and stimulates reactive oxygen species (ROS) production<sup>26</sup>,  
14 which further activates NF- $\kappa$ B leading to inflammation and apoptosis.<sup>27</sup> Therefore, to investigate the role  
15 of AGE-RAGE axis, we have studied the effects of AGE-HSA on cell viability, ROS production and  
16 apoptosis. Cell viability was assessed by 3-(4,5-dimethylthiazol-2-yl)-2,5-diphenyltetrazolium bromide  
17 (MTT) dye reduction assay, an indicator of metabolic status. AGE-HSA was significantly cytotoxic to  
18 neuro2a cells at a concentration of 1.5 mg/ml and above (Figure 1) compared to unmodified HSA, which  
19 was used as a control. Lower concentration of AGE-HSA (0.1, 0.5 and 1 mg/ml) however, did not show  
20 any cytotoxic effects (Figure 1). Therefore, AGE-HSA at a non-cytotoxic concentration of 1 mg/ml was  
21 chosen to conduct all subsequent experiments. Next, the influence of AGE-HSA on ROS production was  
22 studied by 2',7'-Dichlorofluorescein diacetate (DCF-DA) staining. ROS induced formation of fluorescent  
23 2', 7'-dichlorofluorescein was monitored by fluorescent spectrometry. HSA and AGE-HSA stimulation  
24 showed 1.08 and 1.35 fold increase in the levels of ROS respectively as compared to control (Figure 2A).  
25 Images acquired using fluorescence microscope also showed increase in the DCF-DA fluorescence in  
26 AGE-HSA stimulated cells (Figure 2B). Furthermore, AGE-HSA induced apoptosis was studied using  
27 Annexin V-FITC staining followed by flow cytometry. Cells treated with AGE-HSA showed 7 %  
28 apoptotic cells, which is about 2 fold higher than unmodified HSA (Figure 2 C-E).  
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### 48 **AGE-HSA regulates expression of key proteins involved in AD**

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51 Proteomic analysis (SWATH-MS) was performed to better understand the effect of AGE-HSA on  
52 neuronal cells. A spectral library created from tryptic peptides of control and AGE-HSA treated cells  
53 comprised of 1610 proteins (Supplemental Table S2). SWATH analysis revealed expression of 35 up  
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3 regulated (>2 fold) and 36 down regulated (<2 fold) proteins upon AGE-HSA induction compared to  
4 HSA (Supplemental Table S3). Functional annotation by DAVID analysis suggested that the  
5 differentially expressed proteins were involved in diverse biological processes as shown in Figure 3A and  
6  
7 3B. Briefly, up regulated proteins were involved in fatty acid metabolism, proteolysis, lipid metabolism  
8 and redox processes (Supplemental Table S4), while down regulated proteins were involved in mRNA  
9 processing, protein synthesis and transport and cell adhesion. Furthermore, the differentially expressed  
10 proteins were subjected to iRegulon analysis, a cytoscape plugin for prediction of transcription factors  
11 which probably regulate these proteins. It showed that the up regulated proteins might be co-regulated by  
12 transcription factors such as Nfyb, Hsf2 and Gfi1b (Figure 3C), while down regulated proteins might be  
13 co-regulated by transcription factors such as Etv4 and E2f1 (Figure 3D). Protein-protein interaction  
14 network analysis revealed interactions of differentially regulated proteins and were found to be involved  
15 mainly in the lysosomal degradation pathway (Figure 3E). The most notable findings from the proteomic  
16 analysis was the up regulation of number of lysosomal proteins; Cathepsin B (4.83, p=0.04), asparagine  
17 endopeptidase (AEP)/legumain (4.71, p=0.00003) and acid ceramidase (5.40, p=0.003) and the down  
18 regulation of CD147 (0.46, p=0.02), as these proteins have been directly implicated in AD (Figure 3F).

### 35 **AGE-HSA regulates the expression of Cathepsin B and AEP in mouse primary cultured cortical** 36 **neurons through RAGE**

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40 Exposure to AGEs caused 184.51% and 546.87% increase in the expression of Cathepsin B and AEP  
41 respectively in neuro2a cells confirming the initial proteomic analysis (Figure 4A, 4B and 4C). As  
42 Cathepsin B and AEP are directly involved in A $\beta$  formation and tau hyperphosphorylation respectively<sup>28</sup>,  
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47<sup>29</sup>, we also studied the AGE-RAGE-dependent expression of these two proteins in primary cortical  
48 neurons, which is a better model system for investigating the regulation of these proteins. The expression  
49 of RAGE was confirmed in primary cortical neurons by western blotting (Figure S3, supplementary) and  
50 AGE-HSA was not toxic at 1.0 mg/ml as shown by MTT assay (Figure S4, supplementary). Expression of  
51 Cathepsin B and AEP following exposure to AGEs was studied by Western blotting. As predicted,  
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3 Cathepsin B and AEP expression was elevated by 154.78% and 208.64% respectively in response to  
4 AGEs. Significantly, blocking RAGE with an anti-RAGE antibody (H300) abolished AGE-induced  
5 Cathepsin B and AEP expression demonstrating that up regulation requires an AGE-RAGE interaction  
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10 (Figure 4D, 4E and 4F).

### 11 12 **AGE-RAGE interaction increases Cathepsin B-dependent APP processing, $\beta$ -CTF formation and** 13 14 **A $\beta$ generation**

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17 Cathepsin B is a well-characterized lysosomal cysteine protease in mammalian cells which plays an  
18 important role in intracellular proteolysis.<sup>30</sup> It selectively cleaves APP at the Beta-secretase 1 (BACE1)  
19 site<sup>31</sup> and is associated with the accumulation of A $\beta$ <sub>1-40</sub> and A $\beta$ <sub>1-42</sub>. Furthermore, the Cathepsin B inhibitor,  
20 CA074Me, reduces brain A $\beta$  deposition and improves memory deficits in AD animal models by  
21 inhibiting Cathepsin B.<sup>31</sup> Transgenic mice lacking the Cathepsin B gene displayed reduced A $\beta$   
22 deposition.<sup>32, 33</sup> All these studies suggest an important role for Cathepsin B in APP processing and AD  
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pathology. AGEs increase BACE1 expression<sup>34</sup> but effects on Cathepsin B are much less clear. Hence,  
we studied the sensitivity of APP processing to a selective Cathepsin B inhibitor, CA074Me using an  
APP-GAL4 luciferase reporter assay in primary cortical neurons which preferentially reports  
amyloidogenic  $\beta\gamma$ -secretase dependent processing.<sup>35, 36</sup> Exposure to AGE-HSA, but not HSA alone, led to  
a robust increase in luciferase expression that was sensitive to the  $\gamma$ -secretase inhibitor N-[N-(3,5-  
Difluorophenaacetyl-L-alanyl)]-S-phenylglycine t-Butyl Ester (DAPT) suggesting that AGEs couple to an  
amyloidogenic APP processing pathway in neurons (Figure 5A). Notably the AGEs-induced increase in  
luciferase expression was reversed in the presence of Cathepsin B inhibitor CA074Me suggesting that  
AGE-HSA induced increases in APP processing was mediated primarily by Cathepsin B (Figure 5B).  
Furthermore, the anti-RAGE antibody H300 also strongly inhibited APP processing, indicating that AGEs  
increase APP processing via association with RAGE (Figure 5B). Cathepsin B gene knockout mice have  
substantially reduced levels of the C-terminal  $\beta$ -secretase fragment ( $\beta$ -CTF) derived from APP  
processing,<sup>32</sup> hence APP-CTFs were measured after exposure of neurons to AGE-HSA (Figure 5C).



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3 AGE-HSA treatment appeared to increase  $\beta$ -CTF formation compared with control or HSA alone, as seen  
4 as a diffuse band around 10 kDa by Tris-tricine SDS-PAGE followed by Western blot with anti-APP-CTF  
5 antibody. Treatment with the Cathepsin B inhibitor CA074Me or the anti-RAGE antibody H300,  
6 decreased  $\beta$ -CTF formation suggesting that Cathepsin B regulated  $\beta$ -CTF formation is downstream of  
7 activation of the AGE-RAGE axis. Elevated  $\beta$ -CTF levels in neurons could equally be mediated by  $\beta$ -  
8 secretase; therefore, the effect of the BACE1 inhibitor, AZD3293 on AGEs-mediated  $\beta$ -CTF formation  
9 was also investigated. AZD3293 also reduced  $\beta$ -CTF formation and appeared to switch processing to the  
10 formation of  $\alpha$ -CTFs as seen as a diffuse lower molecular weight band. Collectively, these findings  
11 suggest that both Cathepsin B and  $\beta$ -secretase contribute to AGE-mediated  $\beta$ -CTF formation.  
12 Furthermore, in order to determine if activation of the AGE-RAGE axis resulted in  $A\beta$  formation we also  
13 quantified  $A\beta_{1-42}$  levels by ELISA in the growth media of AGE-HSA treated primary cortical neurons.  
14 Exposure of primary cortical neurons to AGE-HSA resulted in a ~two-fold increase in the secretion of  
15  $A\beta_{1-42}$  compared with HSA alone and a ~3-fold increase in  $A\beta_{1-42}$  compared with non-treated control  
16 (Figure 5D). The AGEs-induced increase in  $A\beta_{1-42}$  was reduced by treatment with either CA074Me or  
17 H300 consistent with our hypothesis that AGEs couple to amyloidogenic APP processing through  
18 recruitment of the AGE-RAGE axis and subsequent activation of Cathepsin B. AZD3293 also reduced  
19 AGE-induced  $A\beta_{1-42}$  secretion but this was likely due to a strong inhibitory effect on basal  $A\beta_{1-42}$  levels in  
20 the absence of AGEs which is in general agreement with previous reports that the favoured constitutive  
21 APP processing route in primary neurons is via BACE.  
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#### 44 **AGE-HSA induces tau phosphorylation**

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47 Our initial proteome measurements demonstrated that AGEs up regulate the expression of AEP in  
48 neurons. Previous studies have implicated AEP in hyperphosphorylation of tau via activation of inhibitor  
49 of protein phosphatase 2A (PP2A) involved in dephosphorylation of tau<sup>28, 37</sup> and the AGE-RAGE axis  
50 activates various kinases including Akt, ERKs, GSK3 $\beta$ ,<sup>38</sup> which are also involved in  
51 hyperphosphorylation of tau. Therefore, we assessed the tau phosphorylation status in response to AGE-  
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3 HSA treatment in primary cortical neurons. Neither HSA nor AGE-HSA altered the levels of tau (Figure  
4 6), but enhanced tau phosphorylation, as evidenced by elevated phosphorylation at Serine396 after AGE-  
5 6 HSA stimulation. However, the increase in pTau S396 observed with AGE-HSA was not restored  
7 8 following co-incubation with an anti-RAGE antibody (H300) (Figure 6) suggesting a mechanism of  
9 10 regulation independent of RAGE  
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### 13 14 **Validation of AGE, RAGE, Cathepsin B, AEP and phosphorylation of tau in the AD brain**

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17 CML, a predominant AGE modification<sup>39</sup> was analyzed in human tissue homogenates prepared from the  
18 19 temporal cortex of AD and control brains. A representative western blot of 6 subjects, 3 each of healthy  
20 21 age matched control and AD patients are showed in Figure 7A. Quantification of western blot revealed  
22 23 that there was 1.35 fold increase ( $p=0.1486$ ) in CML modification of proteins in the brain lysate of AD  
24 25 patients as compared to healthy subjects (Figure 7B). Further accumulation of AGEs is associated with  
26 27 elevated RAGE expression.<sup>40</sup> As expected, AD brain showed 1.31 fold ( $p=0.1290$ ) increase in levels of  
28 29 RAGE expression as compared to age matched controls (Figure 7C). Cathepsin B and AEP expression  
30 31 were also markedly increased by 1.82 ( $p=0.0957$ ) and 1.56 ( $p=0.0268$ ) fold respectively in the human AD  
32 33 brain (Figure 7D and 7E) supporting the proteome and functional data obtained in cell models. The  
34 35 elevated expression of AEP was also reflected with increased tau phosphorylation (2.51 fold,  $p=0.1202$ )  
36 37 in AD subjects. Further, levels of RAGE, Cathepsin B, AEP, pTau and CML modified proteins in Normal  
38 39 and AD subjects was normalized with beta-tubulin which revealed significant increase in their levels  
40 41 across the groups (Table 1). To our knowledge, this is the first study that reports increased expression of  
42 43 Cathepsin B and AEP in AD brain.  
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### 47 48 **Discussion**

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51 The RAGE is a multi-ligand transmembrane receptor which interacts with various ligands including  
52 53 advanced glycation end products (AGEs), HMGB, S100, and A $\beta$ . Long-lived proteins are preferentially  
54 55 glycosylated to form AGEs, which interact with RAGE and exacerbate neurodegeneration.<sup>41</sup> The proteasomal  
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3 system is impaired during aging leading to accumulation of modified proteins including AGEs.  
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5 Furthermore, protein glycation is increased in the Cerebrospinal fluid of individuals with AD as compared  
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7 with age-matched controls.<sup>24, 42, 43</sup> Glycated A $\beta$  is hypothesized as a more suitable ligand for RAGE<sup>21</sup> and  
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9 high levels of AGEs are associated with poorer learning in AD mice.<sup>44</sup> Several studies show RAGE  
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11 dependent increase in ROS generation which further activates nuclear factor (NF)- $\kappa$ B.<sup>27</sup> NF- $\kappa$ B plays an  
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13 important role in transducing inflammatory and pro-apoptotic signals.<sup>45</sup> RAGE-dependent activation of  
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15 NF- $\kappa$ B leads to the up-regulation of RAGE itself.<sup>46</sup> Noticeable increase in RAGE levels and oxidative  
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17 damage is observed in the brain of AD subjects suggesting vital role of ROS in the development AD.<sup>8, 47</sup>  
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19 Despite decades of evidences that shows AGEs accumulate during AD, influence A $\beta$  toxicity and  
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21 clearance, and drive changes through redox actions,<sup>48, 49</sup> the precise molecular mechanisms linking AGEs  
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23 to the development and progression of AD pathology are still not well understood. In this study we have  
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25 investigated the change in proteome in response to AGE treatment in neuro2a cells using label free  
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27 quantitative approach (SWATH-MS) to discover new proteins and pathways that lead to AD progression  
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29 downstream of the AGE-RAGE axis. A number of key lysosomal proteins previously implicated in AD,  
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31 including Cathepsin B, asparagine endopeptidase (AEP) and acid ceramidase, were up regulated by  
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33 AGEs. Activation of the AGE-RAGE axis in neurons stimulated Cathepsin B-mediated APP processing  
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35 and increased A $\beta$ <sub>1-42</sub> formation. Furthermore, AGE-RAGE signaling increased expression of AEP and tau  
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37 phosphorylation.  
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41 Cathepsin B, a cysteine protease, is involved in APP processing through its BACE1 activity leading to  
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43 elevated A $\beta$  formation. Inhibitors of Cathepsin B, CA074Me and E64d, have been shown to improve  
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45 memory function by reducing A $\beta$  levels in transgenic mice overexpressing wild type APP.<sup>29, 31</sup> The  
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47 improvement in memory was also demonstrated by Cathepsin B gene knock out in transgenic mice  
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49 overexpressing wild type APP.<sup>32, 33</sup> In our study also we have demonstrated AGE-HSA induced  
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51 upregulation of Cathepsin B in neuro2a, primary cortical neurons, and in brain tissue from individuals  
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53 with AD subjects. Interestingly, higher levels of Cathepsin B have previously been reported in the plasma  
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55 of AD subjects.<sup>50</sup> The increased expression of Cathepsin B was also associated with enhanced  
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3 amyloidogenic APP processing,  $\beta$ -CTF and  $A\beta_{1-42}$  formation all of which were reduced in the presence of  
4 a Cathepsin B inhibitor or by H300 an anti-RAGE antibody. Collectively, this study suggests that  
5 Cathepsin B may have a potential role in aggravating the onset and development of  $A\beta_{1-42}$  pathology in  
6 sporadic AD particularly in association with type II diabetes where elevated levels of AGEs may induce  
7 up regulation of Cathepsin B expression.  
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12 Neurofibrillary tangles, the second major pathological hallmark of AD are characterized by tau  
13 hyperphosphorylation. The deregulation of protein kinases and/or protein phosphatases is probably the  
14 primary cause of elevated tau phosphorylation.<sup>51</sup> Several protein kinases including members of the  
15 MAPK family, GSK-3 $\beta$ , cyclin-dependent kinase 5 (cdk5), can phosphorylate tau and are regulated by  
16 AGE/RAGE axis.<sup>52-54</sup> Methylglyoxal induced AGEs are linked with tau hyperphosphorylation through  
17 GSK-3 $\beta$  and p38 MAPK activation.<sup>55</sup> Protein phosphatase 2A (PP2A) is predominantly associated with  
18 the dephosphorylation of tau. *In vivo* PP2A activity is regulated by a protein called inhibitor-2 ( $I_2^{PP2A}$ ).  
19 The  $I_2^{PP2A}$  is cleaved by asparagine endopeptidase (AEP) into active fragments, N-terminal ( $I_{2NTF}$ ) and C-  
20 terminal ( $I_{2CTF}$ ), which binds to PP2A leading to its inactivation.<sup>37</sup> Hence, elevated expression of AEP is  
21 associated with decreased PP2A activity leading to tau hyperphosphorylation highlighting its potential  
22 role in AD pathology.<sup>28</sup> In this study, we demonstrated AGE-HSA induced up regulation of AEP in  
23 neuro2a and primary cortical neurons. AEP levels were found to be elevated in brain tissue of AD  
24 subjects. The increased expression of AEP was also associated with increased tau phosphorylation which  
25 was not restored by pre-treatment with anti-RAGE antibody suggesting a RAGE independent regulation.  
26 AEP plays a critical role in tau-related clinical and neuropathological changes during aging which  
27 degrades tau, terminate its microtubule assembly function, induces tau aggregation and triggers  
28 neurodegeneration. Hence, inhibition of AEP is a potential therapeutic approach to treat tau-mediated  
29 neurodegenerative diseases.<sup>56</sup>  
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## CONCLUSION

In summary, using label free quantitative proteomics approach (SWATH-MS), a total of 1196 proteins were identified from murine neuro2a cells after HSA and AGE-HSA stimulation. AGE induced differential expression of 71 proteins, of which 35 were up regulated and 36 down regulated. Differentially regulated proteins included Cathepsin B, AEP, acid ceramidase and CD147, all of which have been implicated in AD pathology. Furthermore, AGE-RAGE induced Cathepsin B mediated increase in  $A\beta_{1-42}$  formation was observed highlighting the importance of AGE/RAGE axis in APP processing. In addition to actions on  $A\beta$  pathology, an AGE-RAGE induced increase in tau phosphorylation was also established, perhaps via increased expression and activity of AEP. Individuals affected by AD showed notable increase in the expression of Cathepsin B and AEP signifying their potential deregulation in AD. This study for the first time demonstrates that AGEs regulate both  $A\beta_{1-42}$  generation and tau phosphorylation, the two key hallmarks of AD, following increased expression of lysosomal proteases, thus providing a direct molecular link between the accumulation of AGEs and the development of AD pathology in sporadic disease and particularly in association with diabetes and hyperglycemia.

## METHODS

### Antibodies

Cathepsin B was detected using rabbit anti-cathepsin B antibody (Santa Cruz Biotechnology (SCBT), #sc-6493-R). Asparagine endopeptidase (AEP) was detected using rabbit anti-AEP antibody (Abcam, #ab125286). RAGE was detected by using rabbit anti-RAGE antibody (SCBT, #H-300). APP and APP-CTFs were detected using monoclonal rabbit anti-APP C-terminal antibody (Abcam, #ab32136). Tau was detected using mouse monoclonal anti-tau46 antibody (Cell Signaling Technology (CST), #4019). Tau phosphosite-specific westerns were performed using the mouse monoclonal anti-pS396/PHF13 (CST, #9632) and anti-pSer202, pThr205/AT8 (Thermo scientific, #MN1020) antibodies. Carboxymethylation

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3 of proteins was detected using rabbit anti-CML (Abcam, #ab27684) antibody. Anti-Tubulin Antibody,  
4 beta III isoform (Millipore, #MAB1637) was used as a routine loading control. Anti-mouse (Millipore,  
5 AP124P) and anti-rabbit (Millipore, AP132P) peroxidase conjugated secondary antibodies were used to  
6 detect primary antibodies.  
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## 11 **Cell culture**

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15 Neuro2a cells were purchased from National Centre for Cell Science, Pune, India. Cells were cultured in  
16 DMEM (Himedia, #AL183A) supplemented with 10% heat-inactivated fetal bovine serum (Himedia,  
17 #RM9955) at 37°C in 5% CO<sub>2</sub>.<sup>57</sup> The presence of RAGE in neuro2a cells was confirmed by Western  
18 blotting (Figure S1, Supplementary). Primary cortical neurons were prepared from CD1 mouse embryos  
19 in accordance with UK Home Office Guidelines as stated in the Animals (Scientific Procedures) Act 1986  
20 using Schedule 1 procedures approved by the University of Bath Animal Welfare and Ethical Review  
21 Body. Primary neurons were prepared essentially as described previously.<sup>58</sup> Cortices were dissected from  
22 15-day-old CD1 mouse embryos, and were mechanically dissociated in PBS (Ca<sup>2+</sup> and Mg<sup>2+</sup> free)  
23 supplemented with 6mM glucose, using a serum coated fire-polished glass Pasteur pipette. Cells were  
24 plated into either 12- or 24-well Nunc tissue culture plates, previously coated with 20 µg/ml poly-D-  
25 lysine (Sigma). Neurons were cultured in neurobasal medium (Life Technologies, #12348017),  
26 supplemented with 2 mM glutamine, 100 µg/ml penicillin, 60 µg/ml streptomycin and B27 (Life  
27 Technologies, #10889038) and incubated at 37°C, in high humidity with 5% CO<sub>2</sub>. Under these growth  
28 conditions at 5-10 days *in vitro* (DIV) cells had a well-developed neuritic network and were 99% β-  
29 tubulin III positive and <1% GFAP positive.  
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## 47 **3-(4,5-dimethylthiazol-2-yl)-2,5-diphenyltetrazolium bromide (MTT) dye reduction assay for cell**

### 48 **viability**

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52 The effect of AGEs on cell viability was determined by MTT assay. Neuro2a cells or primary cortical  
53 neurons were incubated with various concentrations of HSA or AGE-HSA (0.1, 0.5, 1, 1.5 mg/ml) for 24  
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3 h and MTT (2.4 mM) (Sigma, #M5655) was then added for a further 3 h at 37°C in a 5% CO<sub>2</sub> incubator.  
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5 After incubation, the culture media was removed by aspiration and formazan crystals were dissolved in  
6  
7 100% DMSO. The absorbance was measured at 550 nm using Bio-Rad iMark microplate reader.<sup>59</sup>  
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### 10 **Measurement of intracellular ROS**

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13 ROS was detected by 2', 7'-dichlorofluorescein diacetate (Sigma, #D6883) staining followed by plate-  
14  
15 based measurement of fluorescence and imaging. As the process of NADPH oxidase activation and ROS  
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17 generation is an instantaneous process via adaptor molecules, ROS measurement was performed after 1h  
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19 of AGE treatment. Cells were treated with HSA or AGE-HSA for 1 h at 37°C. After wash with PBS, the  
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21 cells were stained with DCF-DA (10 μM) for 10 min at 37°C and fluorescence intensity was read using a  
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23 fluorescence microplate reader (Thermo Scientific Varioskan Flash) at 485/528 nm excitation/emission  
24  
25 wavelengths respectively.<sup>60, 61</sup> Further, fluorescent images were captured by microscopy (Life  
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27 technologies, Evos).  
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### 31 **Apoptosis assay**

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34 AGE induced apoptosis was studied using an Annexin V-FITC apoptosis detection kit (Sigma,  
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36 #APOAF).<sup>62, 63</sup> Cells were treated with HSA or AGE-HSA for 24 h and stained with propidium iodide  
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38 (PI) and Annexin V-FITC for 10 min. Carboplatin (10 μM) or methylglyoxal (3 mM) was applied to cells  
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40 to induce either apoptosis or necrosis respectively, followed by PI or Annexin V-FITC Staining. PI and  
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42 FITC fluorescence was measured using an Accuri Flow Cytometer (BD Biosciences) as per the  
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44 manufacturer's instructions. Data analysis was performed using BD Accuri C6 software and the  
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46 percentage of apoptotic cells was determined.  
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### 50 **Sample preparation for Mass spectrometric analysis**

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53 Neuro2a cells were treated with HSA or AGE-HSA (1 mg/ml) for 24 h. Protein extraction was performed  
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55 in 50 mM ammonium bicarbonate buffer containing 0.1% Rapigest SF (Waters, #186001860) followed  
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3 by 30 min incubation on ice with intermittent mixing. Protein concentration was determined using a Bio-  
4 Rad Bradford assay kit. 100  $\mu\text{g}$  of protein was used for digestion. Proteins were denatured by heating at  
5 80°C for 15 min. Further, proteins were reduced and alkylated by 100 mM dithiothreitol at 60°C for 15  
6 min and 200 mM iodoacetamide at room temperature for 30 min respectively. 4  $\mu\text{g}$  of proteomics grade  
7 porcine trypsin (Sigma, # T6567) was added and incubated for 18 h at 37°C. Samples were acidified with  
8 formic acid to stop the digestion; tryptic peptides were desalted by using C18 zip-tips (Millipore,  
9 #ZTC18S096) and concentrated using vacuum concentrator.<sup>64</sup> Peptides were reconstituted in 3% ACN  
10 with 0.1% formic acid before being subjected to LC-MS/MS analysis.  
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### 21 **Liquid chromatography-mass spectrometry analysis (SWATH-MS)**

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23 All samples were analyzed on an AB Sciex Triple-TOF 5600 mass spectrometer coupled with micro LC  
24 200 (Eksigent) in high-sensitivity mode. To generate the SWATH spectral library, peptide digests of each  
25 treatment were analyzed by LC-MS/MS in an Information Dependent Acquisition (IDA) mode. All raw  
26 mass spectrometry data files have been deposited to the PeptideAtlas with the data set identifier  
27 PASS01086. A spectral library was created by combining the files of all the treatments. Accumulation  
28 time for MS and MS/MS was set to 0.25 ms and 0.01 ms respectively and fragmentation was undertaken  
29 using rolling collision energy. MS scans were performed in the mass range of 350-1800 m/z, with a  
30 charge state 2 to 5 and MS/MS was triggered for ions exceeding 120 cps.<sup>65</sup>  
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41 SWATH-MS datasets were acquired (in biological duplicates and technical triplicates) on micro LC-  
42 Triple TOF 5600. The desalted tryptic peptides were injected onto a Eksigent C18-RP HPLC column (100  
43  $\times$  0.3 mm, 3  $\mu\text{m}$ , 120  $\text{\AA}$ ) at the flow rate of 8  $\mu\text{L}/\text{min}$  over 120 min gradient conditions, solvent A (water  
44 with 0.1 % formic acid) and solvent B (ACN with 0.1 % formic acid): held at 97 % A for 5 min, 97-90 %  
45 A over 20 min, 90-70 % A over 70 min, 70-50 % A over 5 min, 50-10 % A over 1 min, at 10 % A for 7  
46 min, 10-97% A over 1 min and held at 97 % A for 11 min. For SWATH-MS data acquisition, the  
47 instrument was tuned to optimize the quadrupole settings for the precursor ion selection window of 25 Da  
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3 wide using 34 windows of 25 Da effective isolation width (with an additional 1 Da overlap) and with a  
4 dwell time of 70 ms to cover the mass range of 350-1200 m/z in 3.4 s. Before each cycle, an MS1 scan  
5 was acquired, and then the MS2 scan cycle started (350–375 m/z precursor isolation window for the first  
6 scan, 374–400 m/z for the second scan 1174–1200 m/z for the last scan). The collision energy for each  
7 window was set using the collision energy of a 2<sup>+</sup> ion centered in the middle of the window with a spread  
8 of 15 eV.<sup>66</sup>  
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### 16 **Protein Identification and Quantification**

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19 To obtain spectral library from IDA runs, data was analyzed by Protein Pilot software 5.0 (1% FDR)  
20 using UniProt *Mus musculus* database containing more than 16500 reviewed protein entries (2015).  
21 Validation was performed through a false discovery rate set to 1% at protein. Specificity of trypsin  
22 digestion was set for cleavage after lysine or arginine. The precursor and fragment initial mass error  
23 tolerance was set to 0.05 Da and 0.1 Da respectively. Spectral library was used as database for the  
24 analysis of SWATH data with MS and MS/MS mass error of 20 ppm and 30 ppm respectively. SWATH  
25 files were exported to Marker View which gives quantitative analysis of proteins, peptides and ions in  
26 different samples.<sup>65</sup>  
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### 37 **Experimental Design and Statistical Rationale**

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40 The data set contains mass spectrometry results from the analysis of 2 biological and 3 technical  
41 replicates of neuro2a cell samples leading to 12 raw files considered for statistical analysis. For each  
42 analyzed sample, the values of the technical replicates were averaged and subjected to the statistical  
43 analysis. The proteins with a minimum 2-fold change (normalized with total intensity) and p values under  
44 0.05 were considered significantly regulated.  
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### 51 **DAVID and Cytoscape analysis**

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3 *Mus musculus* uniprot accessions of differentially expressed proteins were uploaded to functional  
4 annotation tool DAVID and functional clustering and pathway enrichment was performed with high  
5 stringency.<sup>67</sup> Further, differentially regulated proteins were analysed using the iRegulon plugin of  
6 Cytoscape 3.3 to determine proteins under common regulator.<sup>68</sup> The dysregulated proteins were further  
7 analysed for protein-protein interactions using String and closely interacting proteins were identified  
8 using MCL algorithm of Clustermaker2 plugin in Cytoscape.<sup>69</sup>  
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### 16 **Western blotting**

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19 Neuro2a cells or primary cortical neurons were harvested in RIPA buffer (150 mM NaCl, 1 mM EDTA,  
20 1% Triton X-100, 0.5% deoxycholic acid, 50 mM Tris-HCl, pH 7.5), kept on ice with intermittent mixing  
21 and centrifuged at 4°C. 10 µg of protein lysate was separated on 10% SDS-PAGE, transferred onto  
22 polyvinylidene difluoride (Millipore, #ISEQ10100) membrane and incubated for 1 h at room temperature  
23 in blocking buffer containing 3% BSA dissolved in PBST (NaCl 136.89 mM, KCl 2.68 mM, Na<sub>2</sub>HPO<sub>4</sub>  
24 10.14 mM and 0.1% Tween 20). The membranes were incubated overnight at 4°C with primary antibody  
25 in blocking buffer. The following antibodies were used, anti-Cathepsin B (1:500), anti-AEP (1:1000),  
26 anti-RAGE (1:500), anti-tau (1:1000), Anti-pS396Tau (1:1000), AT8 (1:1000) and anti-CML (1:2000).  
27 The membranes were incubated either with anti-rabbit or anti-mouse HRP conjugated secondary antibody  
28 at a dilution of 1:2500 for 60 min at room temperature. Immunodetection was performed using the  
29 Amersham ECL prime (GE Healthcare, RPN2232) western blotting detection reagent following the  
30 manufacturer's instructions.  
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### 45 **Detection of APP695 and APP C-terminal fragments**

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48 Primary cortical neurons cultured in 6-well plates for 7-10 DIV were treated with either HSA or AGE-  
49 HSA, in the presence or absence of anti-RAGE antibody (H300), Cathepsin B inhibitor (Calbiochem,  
50 #205531) and BACE 1 inhibitor (AZD3293) washed twice with cold PBS, and lysed in RIPA buffer,  
51 centrifuged, and protein was quantified. Proteins were resolved by 10% Tris-glycine SDS-PAGE for  
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3 APP695 and by 16.5% Tris-tricine SDS-PAGE for APP C-terminal fragments (CTFs).<sup>36</sup> Following SDS-  
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5 PAGE, proteins were transferred onto 0.2  $\mu$ m PVDF membrane. Western blotting for APP695 and APP  
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7 CTFs (raised against 20 C-terminal amino acids of APP695) was performed using Y188 antibody  
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9 (1:2000). Western blotting for beta tubulin was performed using beta tubulin primary monoclonal  
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11 antibody (1:5000) and HRP-conjugated goat anti-mouse IgG secondary antibody (1:2500). APP695, APP-  
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13 CTFs and beta tubulin were detected using ECL prime advance system, as per the manufacturer's  
14  
15 instructions.  
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### 17 18 **Plasmids**

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21 Three plasmids were used to assess the APP processing by the luciferase reporter assay. Full length APP  
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23 cloned in pRC-CMV-APP695-Gal4 was used as described earlier.<sup>36</sup> Briefly, it is a pRC-CMV vector  
24  
25 encoding a human APP695 fused in-frame at its C-terminus to the yeast transcription factor Gal4 via a  
26  
27 glycine hinge. pFR-Luciferase reporter vector with firefly (*Photinus pyralis*) luciferase gene under the  
28  
29 control of a synthetic promoter containing 5 tandem repeats of the yeast Gal4 activation sequence  
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31 upstream of a minimal TATA box was used. A phRL-thymidine kinase (TK) vector containing sea pansy  
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33 (*Renilla reniformis*) luciferase gene under control of the herpes simplex virus-TK promoter was the third  
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35 vector co-transfected. The latter two plasmids were procured from promega.  
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### 39 **Dual-Glo luciferase gene reporter assay**

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42 pRC-APP695-Gal4 and pFR-Luciferase (0.5  $\mu$ g) were transfected into primary cortical neurons cultured  
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44 in 24-well plates at 5 DIV, using Lipofectamine 2000 (1  $\mu$ L/well). All wells were co-transfected with  
45  
46 phRL-TK-Renilla (0.5  $\mu$ g) as an internal control for luciferase expression. Transfection mixes containing  
47  
48 lipid and DNA were prepared separately in OptiMEM I reduced serum medium (Gibco, #31985062), then  
49  
50 mixed and incubated at RT for 25 min. After incubation, 75  $\mu$ L/well transfection mix was added drop  
51  
52 wise to the cells and incubated for 2 h. In one set of experiment, primary cortical neurons were pre-treated  
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54 with  $\gamma$ -secretase inhibitor, N-[N-(3,5-difluorophenacetyl)-L-alanyl]- (S)-phenylglycine t-butyl ester for 30  
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3 min followed by transfection and treatment with HSA or AGE-HSA for 24 h (Figure 5A). In second set of  
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5 experiment, primary cortical neurons were pre-treated with Cathepsin B inhibitor, CA074-Me or anti-  
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7 RAGE antibody, H300 for 30 min followed by transfection and treatment with HSA or AGE-HSA for 8  
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9 h. Post treatment, quantification of firefly luciferase and renilla luciferase expression was measured  
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11 (Figure 5B). Neurons were lysed with Glo-lysis buffer (50  $\mu$ L/well) (Promega, #E2661), and the Dual-  
12  
13 Glo luciferase activity assay was performed according to the manufacturer's instructions (Promega,  
14  
15 #E2940). Luciferase signals were captured using a microplate luminometer (Promega). Firefly luciferase  
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17 reporters activity was normalized using the renilla luciferase activity, which helps to differentiate between  
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19 specific and nonspecific cellular responses and control for transfection efficiencies across experiments.<sup>35</sup>  
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### 23 **Determination of $A\beta_{1-42}$ release**

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26 To determine the effect of AGE-HSA on  $A\beta_{1-42}$  release from primary cortical neurons, cells were grown  
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28 in 6 well plates, the conditioned neuronal growth medium at 5 DIV was removed, and neurons were  
29  
30 washed twice with warm (37°C) PBS, pH 7.4, to remove  $A\beta$  that had accumulated with time in culture.  
31  
32 Then, 500  $\mu$ l of fresh, warm (37°C) neurobasal medium without phenol red, supplemented with B-27,  
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34 containing either HSA or glycated HSA; in the presence or absence of Cathepsin B inhibitor (CA074Me)  
35  
36 or BACE 1 inhibitor (AZD3293) or Anti-RAGE antibody (H300) was added to the neurons for a further  
37  
38 24 h. The neurobasal medium (300  $\mu$ l) was harvested and transferred to 1.5 ml tubes containing complete  
39  
40 protease inhibitor cocktail and centrifuged at 10,000  $\times$  g for 30 min at 4°C. Samples (200  $\mu$ l) were then  
41  
42 added to a mouse  $A\beta_{1-42}$  ELISA plate and processed for detection of  $A\beta_{1-42}$  according to the  
43  
44 manufacturer's instructions (Invitrogen, #KMB3441).  $A\beta_{1-42}$  levels in conditioned medium were  
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46 calculated from a mouse  $A\beta_{1-42}$  standard curve.  
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### 50 **Human tissue samples**

51  
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53 Human brain tissue homogenates were provided by the London Neurodegenerative Brain Bank which is  
54  
55 funded by grants from the UK Medical Research Council and by Brains for Dementia Research, a joint  
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3 venture between Alzheimer's Society and Alzheimer's Research UK.Brains for Dementia Research has  
4 ethics approval from London–City and East NRES committee 08/H0704/128+5 and all participants gave  
5 informed consent for their tissue to be used in research. Tissue samples from the temporal cortex were  
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dissected from frozen brains of 3 AD cases (age  $84.3 \pm 6.3$  years) and 3 age matched controls (age  $89.3 \pm 11.3$  years) and were homogenised in RIPA buffer at King's College London, UK.

### Statistical analyses

Statistical analyses were performed using either Student's t-test (two-group comparison) or one-way ANOVA. Unpaired t-test was used to study the differential expression of proteins in human brain tissue homogenates of Normal and AD subjects.

### SUPPORTING INFORMATION

Table S1. List of glycated peptides identified by High resolution accurate mass spectrometry

Table S2. List of identified Proteins and peptides

Table S3. List of differentially regulated proteins upon AGE induction

Table S4. Functional annotation of GO Process by DAVID analysis

Supplemental methods and figures

### AUTHOR CONTRIBUTIONS

M.J.K. conceived the idea, designed, supervised the study. M.J.K., K.B.B. and R.W. have written the manuscript. K.B.B. and R.G. carried out the neuro2a cell experiments and have carried out western blotting and proteomic analysis including protein extraction, digestions and mass spectrometric acquisitions. R.M.B. was involved in cytoscape analysis and apoptosis studies, R.W., K.B.B. and O.K. were involved in primary cell culture experiments and analysis. All authors reviewed the manuscript.

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6 fellowship support.  
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12 **CONFLICT OF INTEREST:** Authors declare no conflict of interest.  
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## 15 **ABBREVIATIONS**

16  
17 **AD** Alzheimer's disease

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19 **AEP** Asparagine Endopeptidase

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21 **AGE** Advanced glycation end products

22  
23 **A $\beta$**  Amyloid beta

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25 **APP** Amyloid precursor protein

26  
27 **BACE1** Beta-secretase 1

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29 **CML** Carboxymethyllysine

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31 **CTF** C-terminal fragments

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33  **$\beta$ -CTF** C-terminal fragment of  $\beta$ -secretase cleavage

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35 **DIV** Days in vitro

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37 **DCF-DA** 2',7'-Dichlorofluorescein diacetate

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39 **GSK3 $\beta$**  Glycogen synthase kinase 3 $\beta$

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41 **HSA** Human serum albumin

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43 **PP2A** Protein phosphatase 2A

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45 **RAGE** Receptor for advanced glycation end products  
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47 **SWATH** Sequential window acquisition of all  
48 theoretical fragment ion spectra  
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3 FOXOs and PGC-1 $\alpha$  and Increases in A $\beta$ 1–40/42 and Phospho-Tau May Abet Alzheimer Development,  
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## FIGURE LEGENDS

**Figure 1: Effect of AGEs on the viability of neuro2a cells *in vitro*.** Neuro2a cells were treated with different concentrations of HSA or AGE-HSA (0.1, 0.5, 1.0 and 1.5 mg/ml) for 24 h. The effect of AGEs on the viability of cells was analyzed by MTT assay. One-way ANOVA was used to calculate the variances in HSA and AGE-HSA treated groups.

**Figure 2: Measurement of AGE-HSA induced ROS production and apoptosis in neuro2a cells.** (A) ROS generation after HSA or AGE-HSA stimulation was measured in neuronal cells using H<sub>2</sub>DCF-DA after administration of 1 h. H<sub>2</sub>DCF-DA only treated cells served as control and fold change is presented relative to control measured by spectrofluorometer. (B) Neuro2a cells were treated with control, HSA, or AGE-HSA for 1 h, and DCF-DA fluorescence images were obtained at 30 min after treatment (Upper panel depicts the bright field images while lower panel shows the green field images). Flow cytometric analysis of neuro2a cells treated with (C) HSA or (D) AGE-HSA using Annexin V-FITC Apoptosis Detection Kit. (E) Bar graph depicting the percentage of apoptotic cells upon HSA or AGE-HSA stimulation. FITC, fluorescein isothiocyanate; PI, propidium iodide; BF, bright field; GF, green field. Student's t-test was used to compare ROS generation after HSA and AGE treatments.

**Figure 3: AGE-HSA regulates the expression of several proteins associated with different metabolic function in neuronal cells.** Pathway analysis of (A) up regulated and (B) down regulated proteins upon AGE-HSA stimulation by DAVID. Potential transcription factors co-regulating (C) up regulated and (D) down regulated proteins predicted using cytoscapeplug-in, iRegulon. (E) Protein-protein interactions between deregulated proteins were analysed by using String and closely interacting proteins were identified using MCL algorithm of Clustermaker2 plugin in Cytoscape. (F) Bar graph demonstrating the fold change in the expression of key proteins implicated in AD. (Pathways represented in bar graph are with P<0.05)

**Figure 4: Western blot analysis of Cathepsin B and AEP in neuro2a cells and primary cortical neurons.** The levels of Cathepsin B and AEP expressed were measured in neuro2a cells (shown in A, B

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3 and C) and in primary cortical neurons (shown in D, E and F) after HSA or AGE stimulation. A beta-  
4 tubulin was used to normalize the possible loading errors. (A) Western blot analysis of Cathepsin B and  
5 AEP expressed in the neuro2a cells after AGE stimulation for 24 hours. (B) Quantitative analysis of  
6 Cathepsin B levels detected with Western blot in neuro2a cells. The level of Cathepsin B protein  
7 expressed in control was set as 100%; levels of Cathepsin B expressed after 24 hours of HSA or AGE  
8 stimulation were calculated by comparing to that of control. Densitometric analysis showed a significant  
9 increase in Cathepsin B levels after AGE stimulation. (C) Quantitative analysis of AEP levels detected  
10 with Western blot in neuro2a cells. The level of AEP protein expressed in control was set as 100%; levels  
11 of AEP expressed after HSA or AGE stimulation were calculated by comparing to that of control.  
12 Densitometric analysis showed a significant increase in AEP levels after AGE stimulation. (D) Western  
13 blot analysis of Cathepsin B and AEP expressed in the primary cortical neurons after AGE stimulation for  
14 24 hours. (E) Quantitative analysis of Cathepsin B levels detected with Western blot in primary cortical  
15 neurons. The level of Cathepsin B protein expressed in control was set as 100%; levels of Cathepsin B  
16 expressed after 24 hours of HSA or AGE or H300/AGE stimulation were calculated by comparing to that  
17 of control. Densitometric analysis showed a significant increase in Cathepsin B levels after AGE  
18 stimulation and blocking RAGE with an anti-RAGE antibody (H300) abolished AGE-induced Cathepsin  
19 B expression. (F) Quantitative analysis of AEP levels detected with Western blot in primary cortical  
20 neurons. The level of AEP protein expressed in control was set as 100%; levels of AEP expressed after  
21 HSA or AGE or H300/AGE stimulation were calculated by comparing to that of control. Densitometric  
22 analysis showed a significant increase in AEP levels after AGE stimulation and blocking RAGE with an  
23 anti-RAGE antibody (H300) abolished AGE-induced AEP expression. One-way ANOVA was used to  
24 compare the expression of Cathepsin B and AEP across treatments in neuro2a cells and primary cortical  
25 neurons.

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52 **Figure 5: AGE stimulation increases Cathepsin B-dependent amyloidogenic APP processing in**  
53 **primary cortical neurons through RAGE.** (A) Primary cortical neurons were transfected with plasmid  
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3 encoding pFR-Luc firefly luciferase reporter gene and APP695-Gal4. All cells were co-transfected with  
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5 phRL-TK plasmid that constitutively expresses Renilla luciferase. Dual-Glo luciferase activity assays  
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7 were performed 24 h after HSA or AGE-HSA treatment for quantification of firefly and Renilla luciferase  
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9 expression. Firefly luciferase activity was normalized using the Renilla luciferase activity. Cells were  
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11 treated with 10  $\mu$ M N-[N-(3,5-Difluorophenoacetyl-L-alanyl)]-S-phenylglycine t-Butyl Ester for 30 min  
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13 before transfection. The assay result shows the increased expression of pFR-Luc firefly luciferase upon  
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15 AGE stimulation. (B) Primary cortical neurons were treated with 5  $\mu$ M CA074-Me or 4  $\mu$ g/ml H300 for 30  
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17 min before co-transfection with pFR-Luc firefly luciferase reporter gene, APP695-Gal4 and phRL-TK  
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19 plasmids. Dual-Glo luciferase activity assay was performed 8 h after HSA or AGE-HSA stimulation for  
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21 quantification of firefly and Renilla luciferase expression. Firefly luciferase activity was normalized using  
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23 the Renilla luciferase activity. The assay result shows that pre-treatment of CA074-Me or H300 blocked  
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25 the AGE induced expression of pFR-Luc firefly luciferase. (C) Western blot show the effect of HSA,  
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27 AGE-HSA, CA074Me, H300 or AZD3293 (BACE1 inhibitor) on APP-CTFs formation. (D) ELISA result  
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29 show the elevated release of  $A\beta_{1-42}$  from primary cortical neurons after AGE-HSA stimulation which was  
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31 decreased with pre-treatment of CA074-Me, H300 and AZD3293. \* $P < 0.05$ , \*\* $P < 0.005$ , \*\*\* $P < 0.0005$ ,  
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33 \*\*\*\* $P < 0.00005$ . One-way ANOVA was used to compare the  $A\beta_{1-42}$  formation across control and  
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35 treatment groups.  
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40 **Figure 6: Western blot analysis of phosphorylated and total tau in primary cultured cortical**  
41 **neurons.** The levels of tau and pTau were measured in primary cortical neurons (shown in A, B and C)  
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43 after HSA or AGE-HSA or H300/AGE stimulation. A beta-tubulin was used to normalize the possible  
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45 loading errors. (A) Western blot analysis of Tau and pTau after HSA or AGE or H300/AGE stimulation  
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47 for 24 hours. (B) Quantitative analysis of Tau levels detected with Western blot in primary cortical  
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49 neurons. The level of Tau protein expressed in control was set as 100%; levels of Tau expressed after 24  
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51 hours of HSA or AGE or H300/AGE stimulation were calculated by comparing to that of control.  
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53 Densitometric analysis showed a no change in the expression of Tau levels after AGE stimulation. (C)  
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3 Quantitative analysis of pTau levels detected with Western blot in primary cortical neurons. The level of  
4 pTau protein in control was set as 100%; levels of pTau expressed after 24 hours of HSA or AGE or  
5 H300/AGE stimulation were calculated by comparing to that of control. Densitometric analysis showed a  
6 notable increase in pTau levels after AGE stimulation. One-way ANOVA was used to study the levels of  
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Tau and pTau in control and treatment groups.

**Figure 7: Representative western blot analysis of brain tissue lysates from the temporal cortex of AD subjects compared with age matched controls.** (A) The levels of glycosylated proteins (CML modified), RAGE, Cathepsin B, AEP and pTau were measured in normal and AD subjects. Raw intensity values (without normalization) are plotted for the quantitative analysis of western blots. (B) Quantitative analysis of carboxymethylated protein levels detected with Western blot in Healthy and AD subjects. Densitometric analysis showed a notable increase in glycosylated protein levels in AD subjects. (C) Quantitative analysis of RAGE expression detected by Western blot in Healthy and AD subjects. Densitometric analysis showed elevated RAGE expression in AD subjects as compared to Normal. (D) Quantitative analysis of Cathepsin B protein levels detected by Western blot in Healthy and AD subjects. Densitometric analysis showed increased levels of Cathepsin B in AD subjects. (E) Quantitative analysis of AEP protein levels detected by Western blot in Healthy and AD subjects. Densitometric analysis showed elevated levels of AEP in AD subjects than healthy individuals. (F) Quantitative analysis of pTau levels detected by Western blot in Healthy and AD subjects. Densitometric analysis showed elevated levels of pTau in AD subjects than normal individuals. The unpaired t-test was used to study the differential expression of proteins in human brain tissue homogenates.



**TABLES AND FIGURES**

**Table 1:** Levels of RAGE, Cathepsin B, AEP, pTau and CML modified proteins in Normal and AD subjects normalized with beta-tubulin.

Data is expressed as Mean  $\pm$  SEM.

Sr. No.	Protein Name	Ratio to $\beta$ -tubulin		<i>p</i> Value
		Normal	AD	
1	CML	0.72 $\pm$ 0.39	11.75 $\pm$ 3.99	0.0513
2	RAGE	0.35 $\pm$ 0.22	4.73 $\pm$ 1.3	0.0299
3	Cathepsin B	0.17 $\pm$ 0.10	3.09 $\pm$ 0.95	0.0388
4	AEP	0.18 $\pm$ 0.08	3.35 $\pm$ 1.22	0.0615
5	pTau	0.12 $\pm$ 0.06	3.16 $\pm$ 0.75	0.016

Figure 1

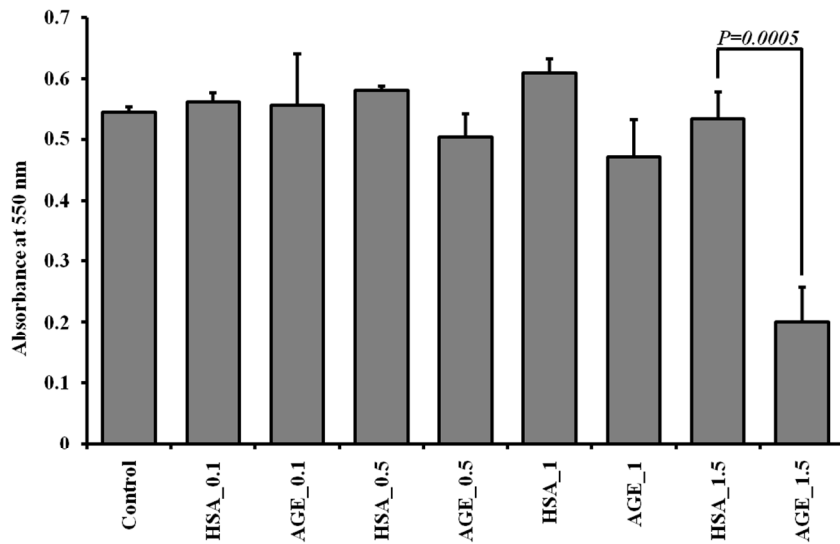


Figure 2

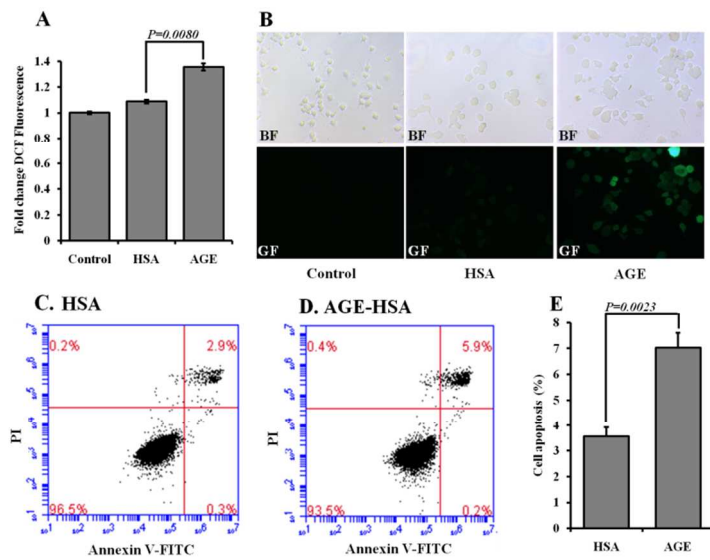


Figure 3

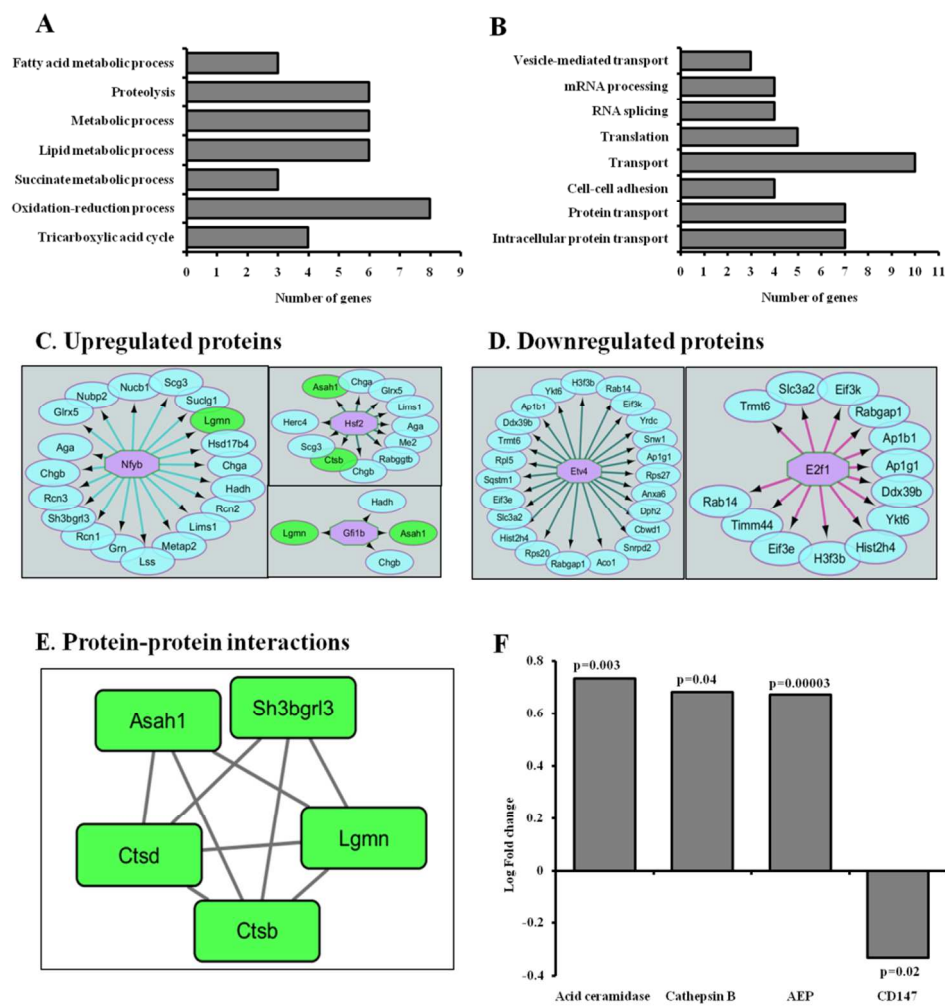


Figure 4

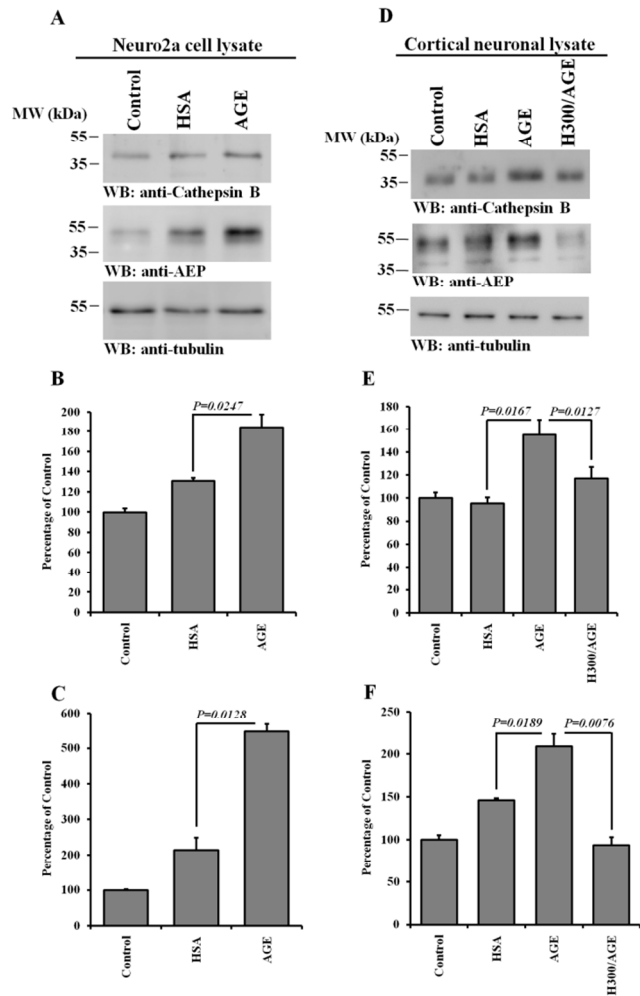


Figure 5

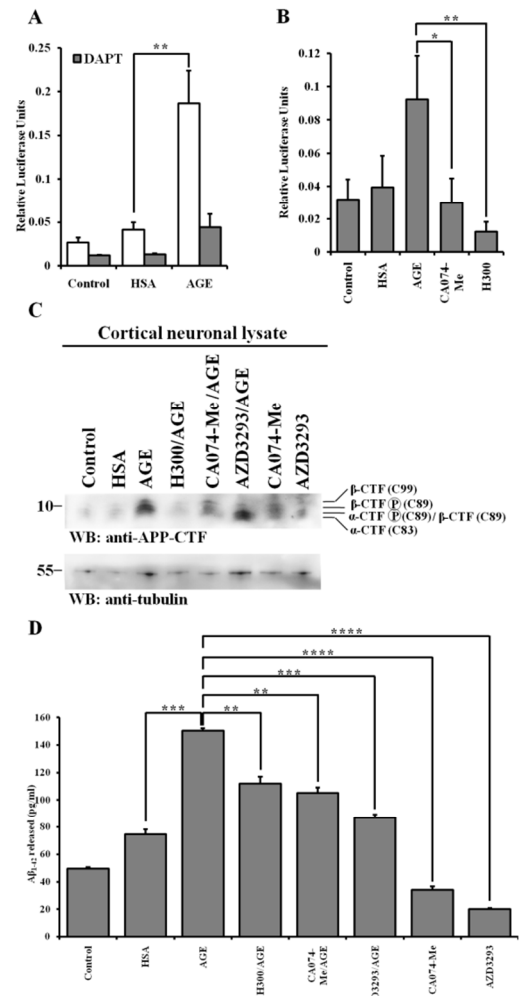


Figure 6

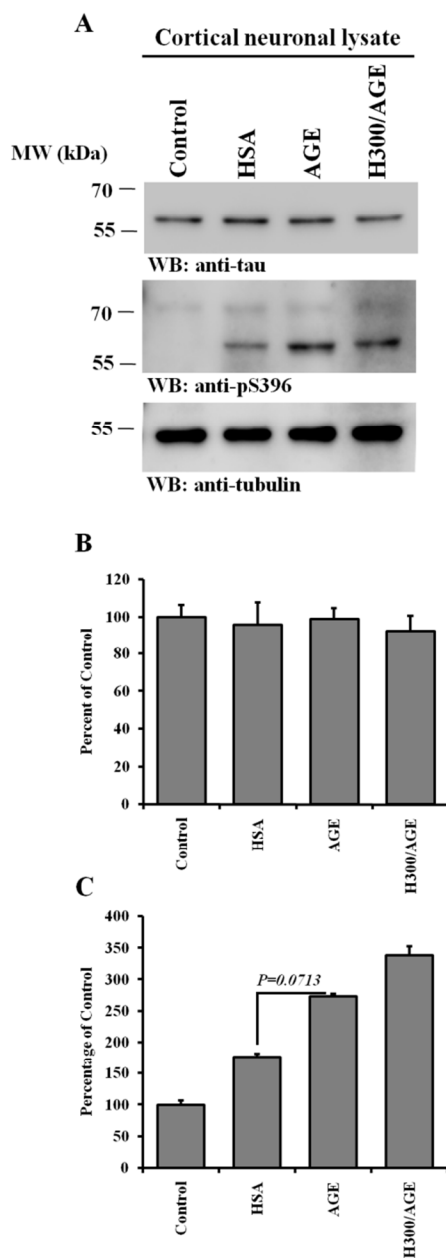
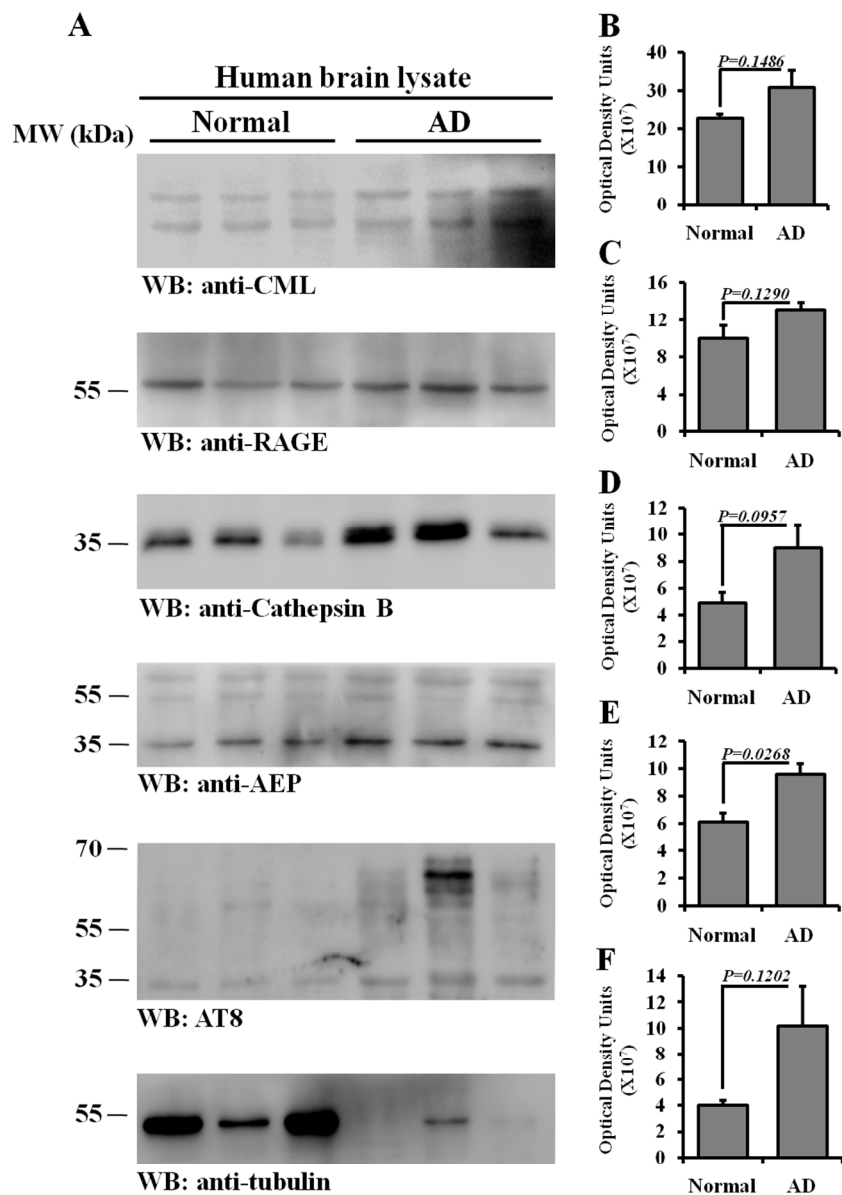


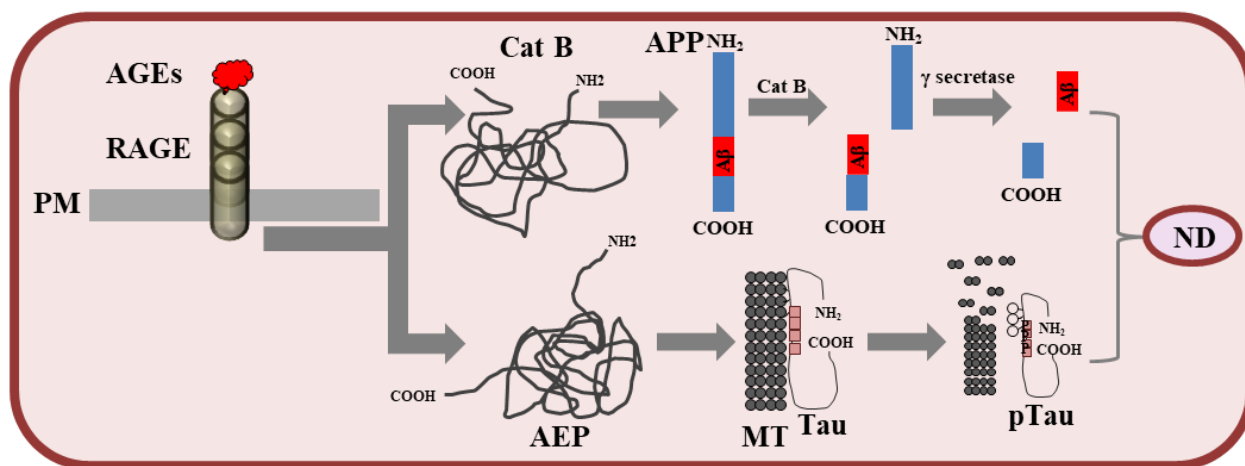
Figure 7



## For Table of Contents Use Only

**Advanced glycation end products modulate amyloidogenic APP processing and Tau phosphorylation: a mechanistic link between glycation and the development of Alzheimer's disease**

Kedar Batkulwar, Rashmi Godbole, Reema Banarjee, Omar Kassar, Robert J Williams, Mahesh J Kulkarni



**TOC Graphic:** AGEs induce the expression of Cathepsin B and AEP causing increased A $\beta$  formation and Tau phosphorylation respectively resulting in neuronal damage. (PM-Plasma membrane, Cat B-Cathepsin B, APP-Amyloid precursor protein, AEP-Asparagine endopeptidase, MT-Microtubules pTau- Phosphorylated Tau and ND-Neurodegeneration).