

Supplemental Information

Supplemental Figure and Table Legends

Figure S1. Measures of frequently used cognitive and pathology scoring for LOAD in ROS/MAP participants in this study, related to Figure 1. Shown are data relating (A) MMSE, (B) global pathology, (C) Braak score, and (D) CERAD score. Shown in red are individuals with a clinical and neuropathological diagnosis of AD. Samples are ordered by global cognition at last visit. E) Table of metrics with statistical tests comparing individuals for whom iPSC lines were generated relative to the larger cohorts. Histograms showing the distribution of age at death (F), neuritic plaque score (G), and tau tangle score (H). Pie charts showing distribution across categories (I), sex (J), and APOE haplotype (K). Histograms showing distribution of global cognition at the last visit prior to death (L), the slope of global cognition over age (M) and MMSE score at last visit (N). LP=low pathology, no pathological AD diagnosis, HP=high pathology, pathological AD diagnosis, NCI=not cognitively impaired, AD= Alzheimer's dementia diagnosis.

Figure S2. Overview of quality control standards of ROSMAP iPSC lines required for inclusion in this study, related to Figure 1. A) Table of QC standards. B) Cell line expansion strategy for generating large numbers of synchronized d21 iN cultures while keeping passage numbers low.

Figure S3. Quality control metrics of iPSCs and neuronal differentiation, related to Figure 2. (A) Mean doubling time is graphed for each iPSC line and shows that doubling times are consistent with pluripotent stem cells and consistent across lines. Shown is mean +/-SD. Number of wells analyzed for each line is shown. (B) Heat map showing relative expression of cell fate markers in iNs across lines, determined mass spectrometry. There were no significant differences in cell fate marker gene expression between iNs derived from NCI and AD individuals (t-test, with Holm-Sidak multiple comparisons test; q-values all >0.75). (C-F) Example Incucyte analysis of cell density and neurite length over differentiation time. Following thaw at d4 of NGN2-induced differentiation, cells were counted and plated at equivalent densities (n=3 wells per line) and monitored for quality control purposes in an Incucyte automated live cell imaging incubator every 2 hours for 4 days. Cell body number and neurite length per cell body number were calculated, and those lines falling outside of 2 SD from the mean density were excluded from further analysis. Shown here is a representative example for such an analysis showing neurite length over time (C) and cell body cluster number over time (D). These analyses show no evidence for differences across categories in either cell body number or neurite length (E,F).

Figure S4. Differential RNA and protein expression between males and females in iNs and brain tissue, related to Figure 3.

(A) RNAseq data from iNs were examined to determine genes differentially expressed between males and females. Out of 16,597 genes quantified, 43 showed differential expression (q<0.05), volcano plot shown. Of these, 10 (shown in red) also are differentially expressed in the brain between males and females (ROS/MAP RNAseq data from PFC, differential expression determined following regression for RIN, PMI, age and diagnosis). Volcano plot of RNAseq analysis in brain shown in (B). (C-H) Examples of genes differentially expressed both in iNs and brain are shown: (C,F) XIST, (D,G) PUDP, and (E,H) USP9Y. (I) Proteomic data was acquired from iNs, and differential protein expression determined between males and females, two-stage linear step-up procedure of Benjamini, Krieger and Yekutieli. Volcano plot (I) shows proteins

showing a trend toward differential protein expression in iNs, in red are those proteins that are also differentially expressed in the postmortem brain. J) Proteomic data from human brain (ROS/MAP) was analyzed to examine male versus female differences (256 female, 115 male; 4,291 proteins analyzed). K-P) Examples of comparisons of protein expression between males and females in both iNs and brain: K,N) UBA1, L,O) SYAP1, and M,P) USP9X.

Figure S5. Differential protein expression and gene ontology analysis between NCI and AD iNs and brain tissue, related to Figure 4. (A) PCA plots of RNAseq and proteomics for iNs and brain datasets. All data was used to generate the PCA blots. AD individuals do not cluster together in iNs or brain datasets. B-K) Violin plots of a subset of proteins identified by analyses comparing LP-NCI and AD and HP- NCI vs AD showing data from iNs (B-F) and DLPFC (G-K). Significance determined by Kruskal- Wallis test with Dunn's multiple comparison's test. L) GO enrichment analyses of proteins differentially expressed between LP-NCI and AD in iNs ($p < 0.05$) showed enrichment in terms related to protein localization and translation. This enrichment was driven in part by a reduction of a large number of ribosomal proteins of both the 40S and 60S subunits when comparing AD to LP-NCI iNs. In addition, proteins relevant to intracellular transport and localization were enriched in AD iNs. We then compared the proteomics GO enrichment observed in iNs to terms enriched in a proteomic data set from postmortem ROSMAP brains (388 individuals) comparing LP-NCI vs AD. The same GO terms also were significantly enriched in the postmortem brain dataset. (M-N) Differential strength of connections within the skyblue module across diagnostic categories. The skyblue module was the only module found to be downregulated in AD iNs relative to both LP-NCI and HP-NCI iNs. In order to examine associations between proteins within this module across categories, Pearson correlation analysis was performed between proteins within the skyblue module with data from NCI or AD iNs. Heat maps of the correlation coefficients show stronger correlations between proteins in AD iNs (M) compared to NCI iNs (N), which is reflected in a significant change in the distribution of Pearson r values for AD vs LP-NCI and AD vs HP- NCI (O). Kruskal-Wallis test with Dunn's multiple comparisons test: LP-NCI vs AD $p < 0.0001$; HP- NCI vs AD $p < 0.0001$; LP-NCI vs HP-NCI $p = 0.66$. (P-Q) In order to examine associations between proteins within each module and the relationship across modules, Pearson correlation coefficients were calculated between each protein present in the modules shown for both iNs (P) and brain (Q). Heat maps of correlation coefficients across proteins show that for some modules, there are highly concordant patterns of association within modules between brain and iNs while others (such as those enriched in glia cell genes) show no such concordance.

Figure S6. Consistency of A β measurements across independent NGN2-inducible iPSC lines from the same individuals and plating densities, related to Figure 5.

(A-D) We determined whether the extent to which the generation of NGN2-inducible lines and the differentiation batch affects the relative levels of A β measured. To this end, NGN2-inducible lines were independently generated over six months and differentiated multiple times to neuronal fates with different lots of NGN2-virus and media components for four parental iPSC lines. A β 38, 40 and 42 were measured in the media of the cells following two days of conditioning. Across these two sets of NGN2-inducible lines, we found that the rank order of A β 42 levels and the ratio of A β 42 to A β 40 levels (A β 42:40) was identical. However, the absolute value of A β peptides was variable. We previously showed that this phenomenon is likely due to lot-to-lot variability in the ELISA kits and synthetic A β peptide standards used to quantify A β [11]. Therefore, the data acquired on A β levels were normalized to eliminate ELISA batch effects in all subsequent analyses. (E-I) Linear relationship between density of iN plating and A β levels. A potential confounding factor when comparing across cell lines is the final density of plating. Despite efforts to plate the same number of viable cells across lines, subtle

differences can still arise. Therefore, we assessed whether relative A β levels (e.g., 42:40) were sensitive to differences in cell density, and whether extracellular A β levels in the media were proportional to the density of the neuronal cultures. To examine the effects of density on extracellular A β levels, two iPSC lines were plated at increasing densities, and A β levels were measured in the media following 48 hours of conditioning. A linear relationship was observed, suggesting that the level of each A β species (38, 40 and 42) was directly proportional to the plating density. We found that density affects the relative levels of different A β species, with increasing densities to 50K cells per well of a 96-well plate showing slightly lower 42:40 ratio. However, plating cells above this level (2-fold higher) did not further affect A β 42:40 (I). Therefore, we conducted all subsequent experiments using a plating density of 50K cells per well of a 96 well plate. (J-K) Relative levels of A β peptides measured in this study. Shown are A β data (J) and sAPP α and sAPP β data (K) acquired via ELISA from d21 iNs across several ROSMAP iPSC lines for a single experiment to relay the relative levels of A β peptides measured. Extracellular A β peptides n=51, intraA β peptides n=39, sAPP species n=39. The caveat of these data is that relative measurements between A β 37, 38, 40 and 42 are potentially confounded by differential aggregation of the standards. However, comparisons between extra and intra A β have no such confound.

Figure S7. Association of intraA β 42:40 and proteins involved in regulation of RNA, proteasome activity, cytoskeleton, and vesicle-mediated transport, related to Figure 5. IntraA β 42:40 shows the strongest association with neuritic plaque score, ($r=0.45$, $p=0.0021$). (A) Bar graph of intraA β 42:40 for each individual across differentiations (mean +/- SEM shown). (B) Scatter plot of mean of IntraA β 42:40 for each individual across the three pathology/diagnostic categories. One-way ANOVA with Tukey's multiple comparisons test comparing across categories. * $p=0.02$, ** $p=0.002$. (C) Spearman correlation coefficients were calculated between intraA β 42:40 and proteomic data from iNs (n=39 individuals, 1115 proteins quantified). Dotted red lines show significance threshold with multiple comparisons ($p=4.5 \times 10^{-5}$) and threshold for suggestive hits that were used in GO analysis (Table S4). (D,E) Individual data points for each line showing correlation between intraA β 42:40 and each two of the significant hits: TMEM35A (G) and SF3B2 (H). (F,G) Correlations between levels of APP cleavage products in d21 iNs. APP cleavage products were measured for iNs generated from 50 iPSC lines over 3-12 differentiation rounds (average of 7) with 2-3 wells quantified per differentiation. Following batch correction, a composite estimate was generated for each metric by taking the mean value across differentiation rounds. Spearman correlation coefficients between APP cleavage products across genetic backgrounds (i.e. different lines) were calculated and are plotted to show Spearman rho value (color of circle) and p-value (size of circle) (F,G). (F) Extracellular levels of A β 38, 40 and 42 were highly positively correlated with one another, while each were strongly negatively correlated with A β 37. (G) Full correlation plot of all APP cleavage products with each other.

Figure S8. Detection of HMW tau using additional tau antibodies in iPSC-derived neurons, related to Figure 5. In order to further characterize the HMW bands of tau detected in iNs, WBs were performed to compare the banding pattern observed in iNs (d21) compared to dual SMAD EB-derived neurons (d100). In addition to AT8 and K9JA, p217 (Genetex) and AT270 (pT181, ThermoFisher Scientific) tau antibodies also were employed. Red arrowheads point to area of HMW tau (>191 kDa MWM).

Figure S9. No association between age at PBMC collection or any single LOAD GWAS SNP with A β 42:37 or tau, related to Figure 6. (A-C) Spearman correlations were calculated between age of PBMC collection and measures from iNs including A β 42:37 (A), Tau aggregate

score (B) and A β +Tau aggregate score (C). (D) Table of rare coding variants found in genes associated with AD. (E) Volcano plot showing a lack of association of LOAD-associated GWAS SNPs with A β 42:37. (F,G) Scatter plots showing relationships between APOE haplotype and tau aggregate score (F) or A β 42:37 (G) measured in iNs, (trends not significant). (H) AIP protein levels in iNs across APOE haplotypes. (I) The top associated LOAD GWAS SNP with tau aggregate score was one at the CD2AP locus. Shown is a scatter plot of the tau aggregate score across iNs relative to copy number of this LOAD risk SNP.

Figure S10. APOE genotype does not affect phospho-tau levels in NGN2-iNs, related to Figure 7.

An isogenic series of iPSC lines (Alstem) were differentiated to neuronal fate via NGN2-induction. At d21 neurons were lysed and Western blots performed to quantify pTau (AT8) and tau levels (K9JA, Dako). Three independent differentiations were analyzed, with n=3 wells analyzed per differentiation. Shown are example WBs, and quantification of data. One-way ANOVA was performed with Tukey's multiple comparisons test, p-values listed.

Figure S11. Protein phosphatase 1 (PP1) levels and activity regulate ptau levels in neurons, related to Figure 7. (A-B) Lysates of iNs from eight individuals spanning the range of PPP1CA expression were collected in an independent round of differentiation and levels of PPP1CA analyzed by Western blot. Rank order levels of PPP1CA were identical between Western blot and proteomics (Spearman $r=1.0$; $p<0.0001$). (C-E) INs derived from five iPSC lines were treated with tautomycin (1 μ M) or vehicle (DMSO) for 24 hrs (d20-d21). WBs performed to measure levels of proteome-wide phospho-ser/thr (C) and media analyzed by ELISA to measure A β levels (D). Data show mean \pm SEM from 7 differentiations, 5 iPSC lines (BR21, BR89, BR04, BR40, BR60), n=18 wells per condition, each line normalized to vehicle. Student's t-test, * $p<0.05$. In addition, WB were run to quantify p-tau and total tau from five LP-NCI lines and five AD lines. Example WBs from LP-NCI iNs are shown in Figure 7 and from AD lines here (E) and all data quantified in Fig.7. (F,G) qPCR was performed to quantify levels of PPP1CA and PPP1R1A RNA following treatment with TauT, PF-06442609 or FeFb (normalized to GAPDH). Treatment with TauT (1 μ M) for 24 hours significantly elevated PPP1CA RNA levels (F) with no effect on PPP1R1A (G). One-way ANOVA with Tukey's multiple comparison's test, n=4-8, **** $p<0.0001$. (H) BR27 (AD) iNs were treated for the last two weeks of differentiation with PF0644206 or vehicle. For the last 48 hr, a subset of these treated wells also were treated with TauT (1 μ M). Following treatments, cells were lysed and tau analyzed by WB. Shown are the mean \pm SEM, n=6, One-way ANOVA with Tukey's multiple comparison's test. * $p<0.05$, ** $p<0.005$. (I) AD iNs were treated with 10 μ M C2-ceramide for 48 hours and then lysed and tau analyzed by WB. Data shows mean \pm SEM, n=3-6 wells per condition, data normalized to vehicle within each line.

Figure S1.

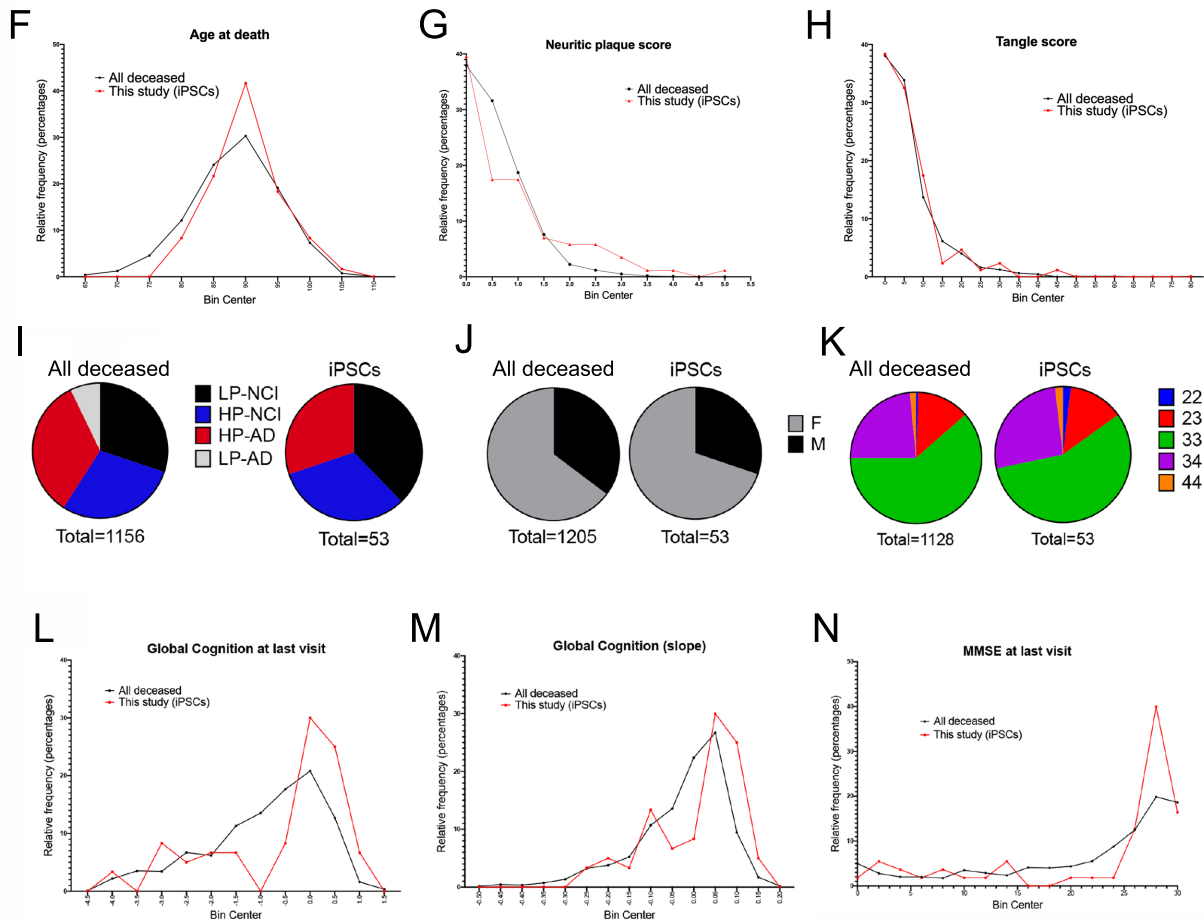
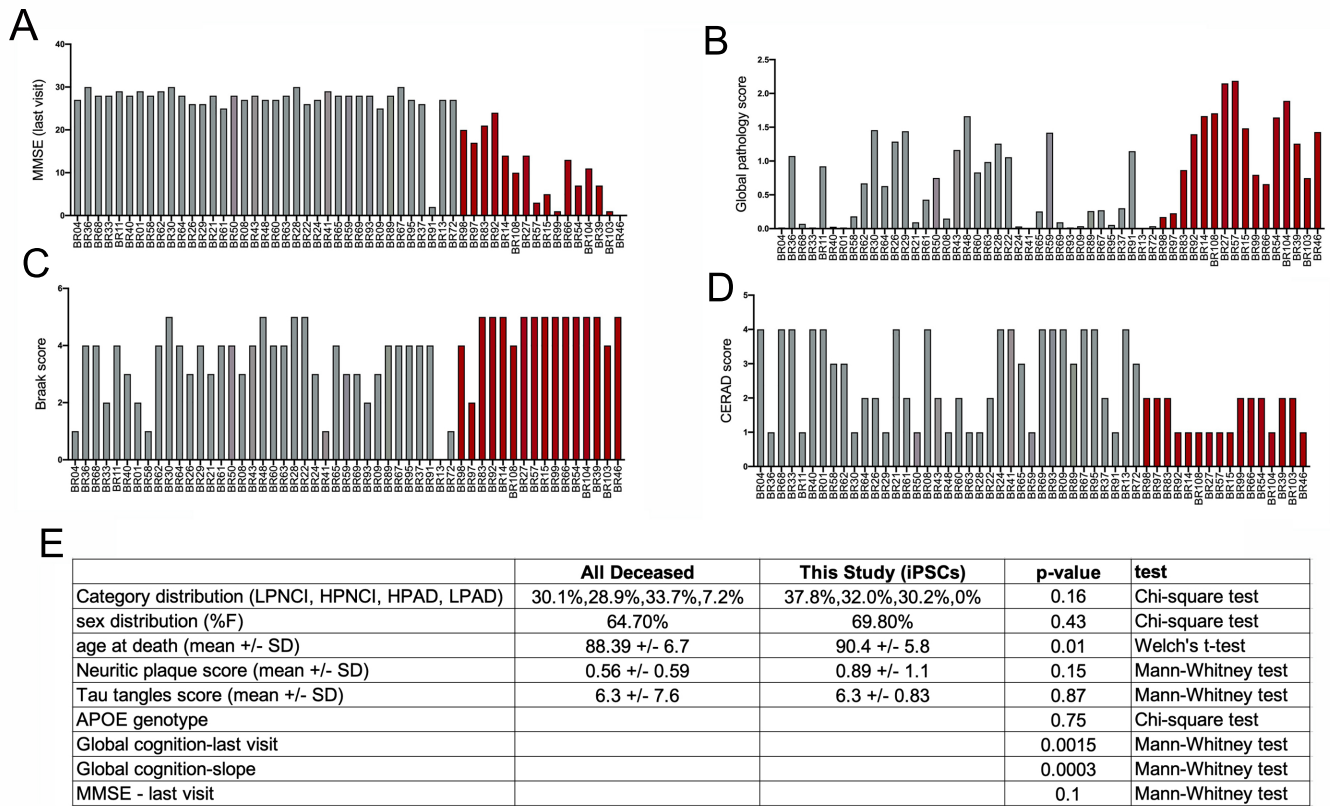


Figure S2.

A

Test Description	Test Method	Test Specification
Post-Thaw Viable Cell Recovery	Automated cryotube thaw to 6 well plate	>50% Confluency within 10 days
Sterility	SteriTEQ	Negative
Mycoplasma	Lonza MycoAlert Plus	Negative
Karyotype	Illumina CoreExome-24	Normal Karyotype (No Autosomal CNVs > 2.5MB)
Identity Match	Fluidigm SNPTrace Analysis	Match parent fibroblast line
Pluripotency Expression profile	Nanostring Pluripotency Scorecard Analysis	Express Markers of pluripotency with absence of early differentiation markers
Shutoff Sendai transgenes	Nanostring Gene Expression Analysis	Absence of Sendai Virus Expression
Differentiation Capacity	Nanostring 3 Germ Layer Scorecard Analysis	Absence of bias differentiation into any of three germ layers

B

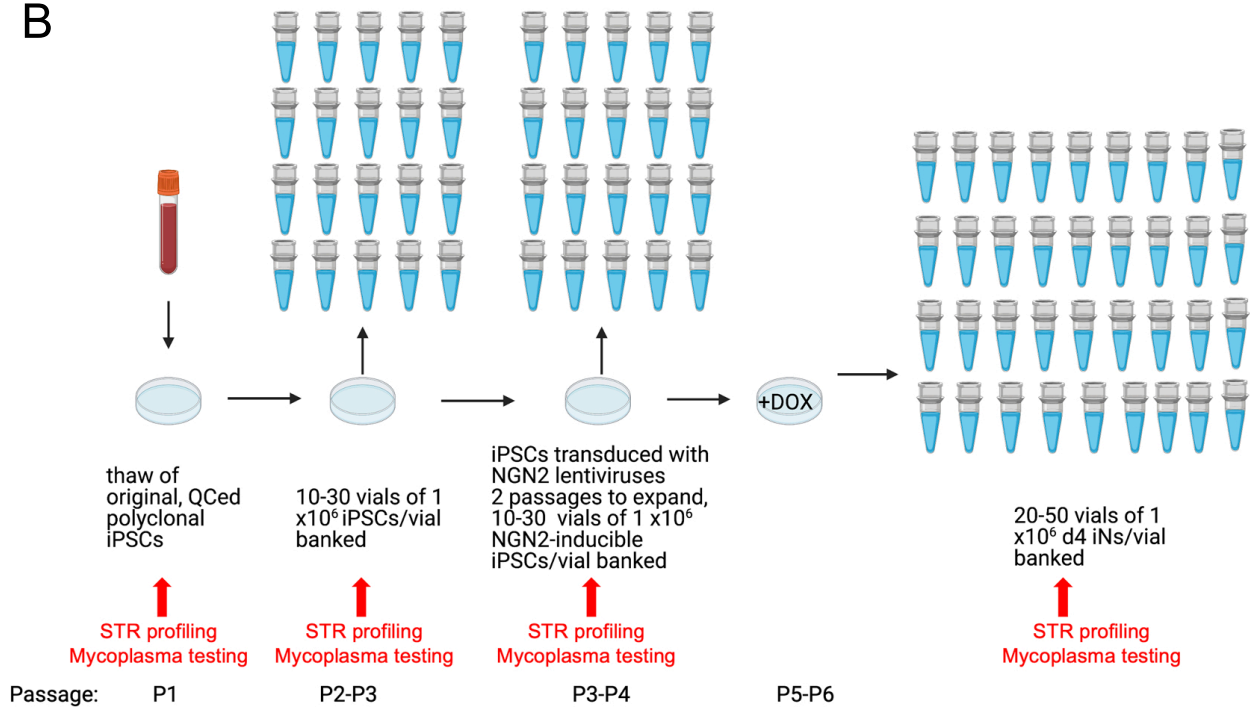
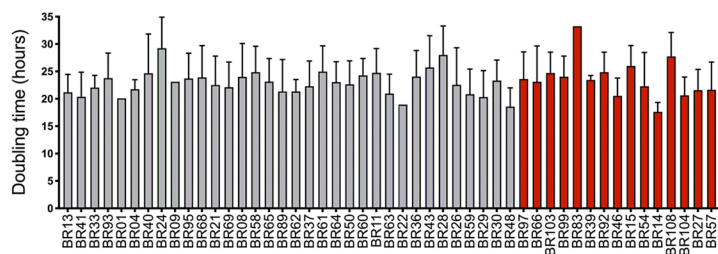


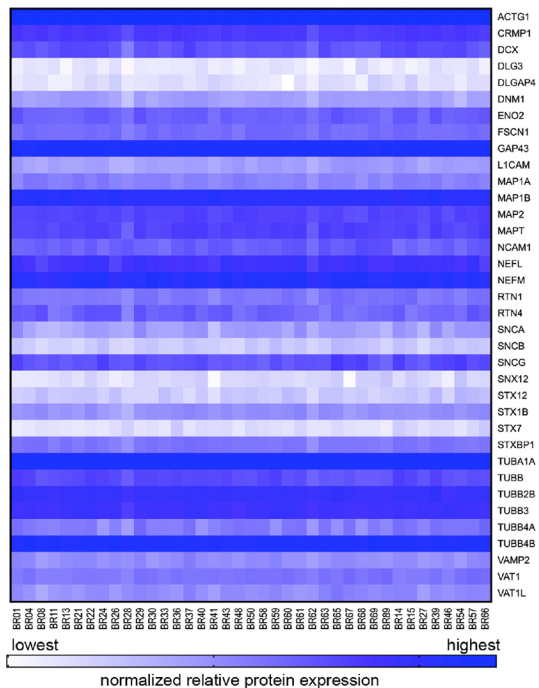
Figure S3.

A

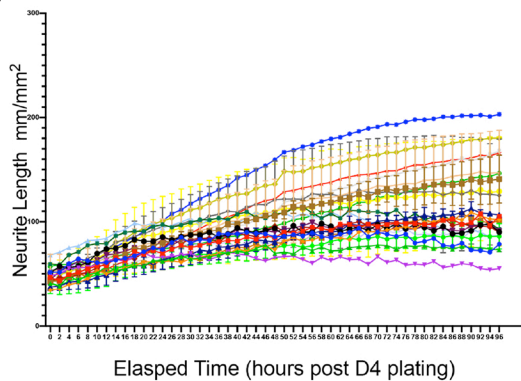


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BRID:	BR21	BR69	BR08	BR58	BR65	BR89	BR62	BR37	BR61	BR64	BR50
n=	35	10	31	27	19	24	18	43	31	41	
BRID:	BR60	BR11	BR63	BR22	BR36	BR43	BR28	BR26	BR59	BR29	BR30
n=	38	22	37	1	8	20	22	5	9	10	11
BRID:	BR48	BR97	BR66	BR103	BR99	BR83	BR39	BR92	BR46	BR15	BR54
n=	29	52	25	66	1	2	87	14	30	8	
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n=	12	157	143	20	14						

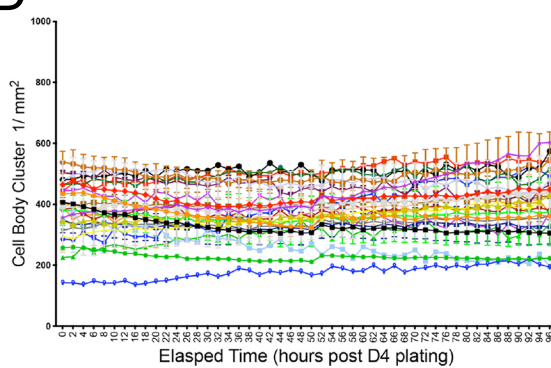
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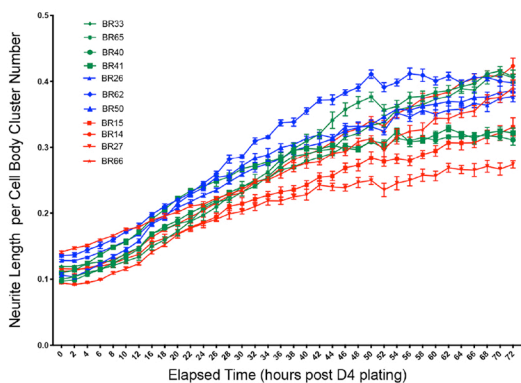
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D



E



F

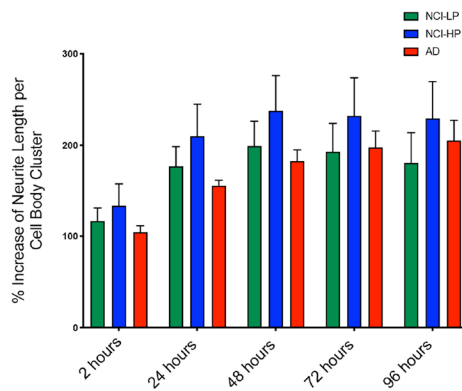


Figure S4.

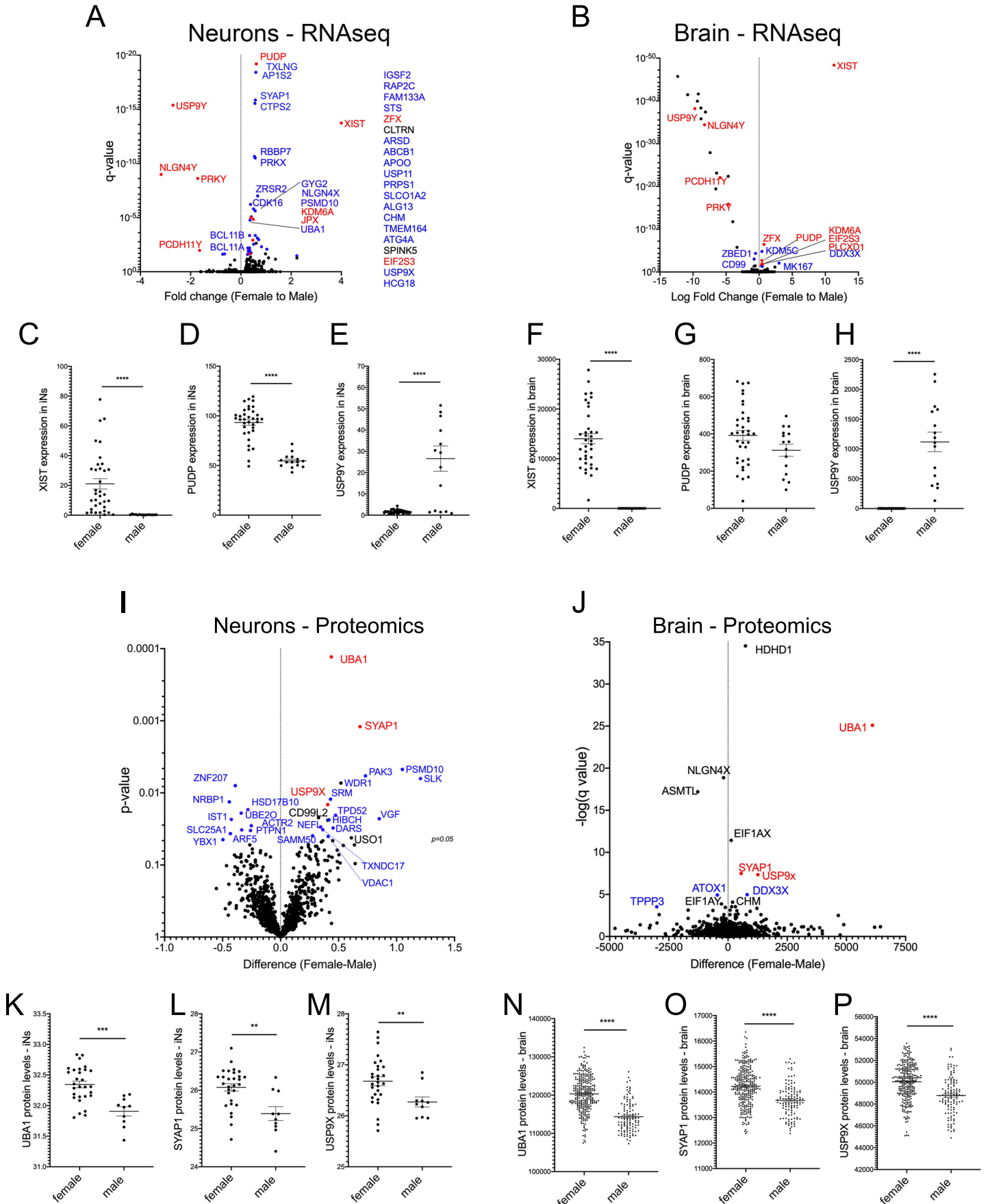


Figure S5.

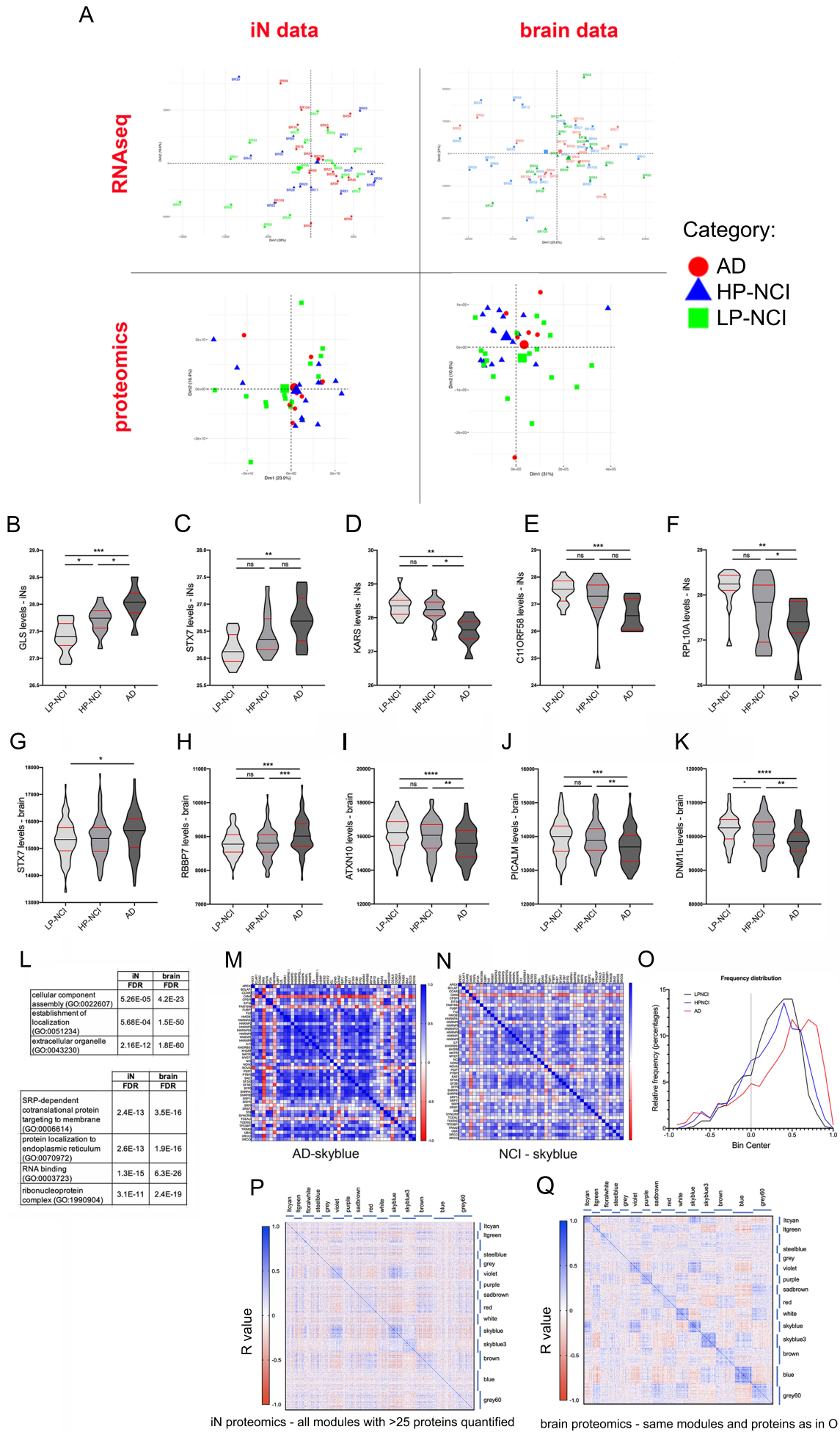


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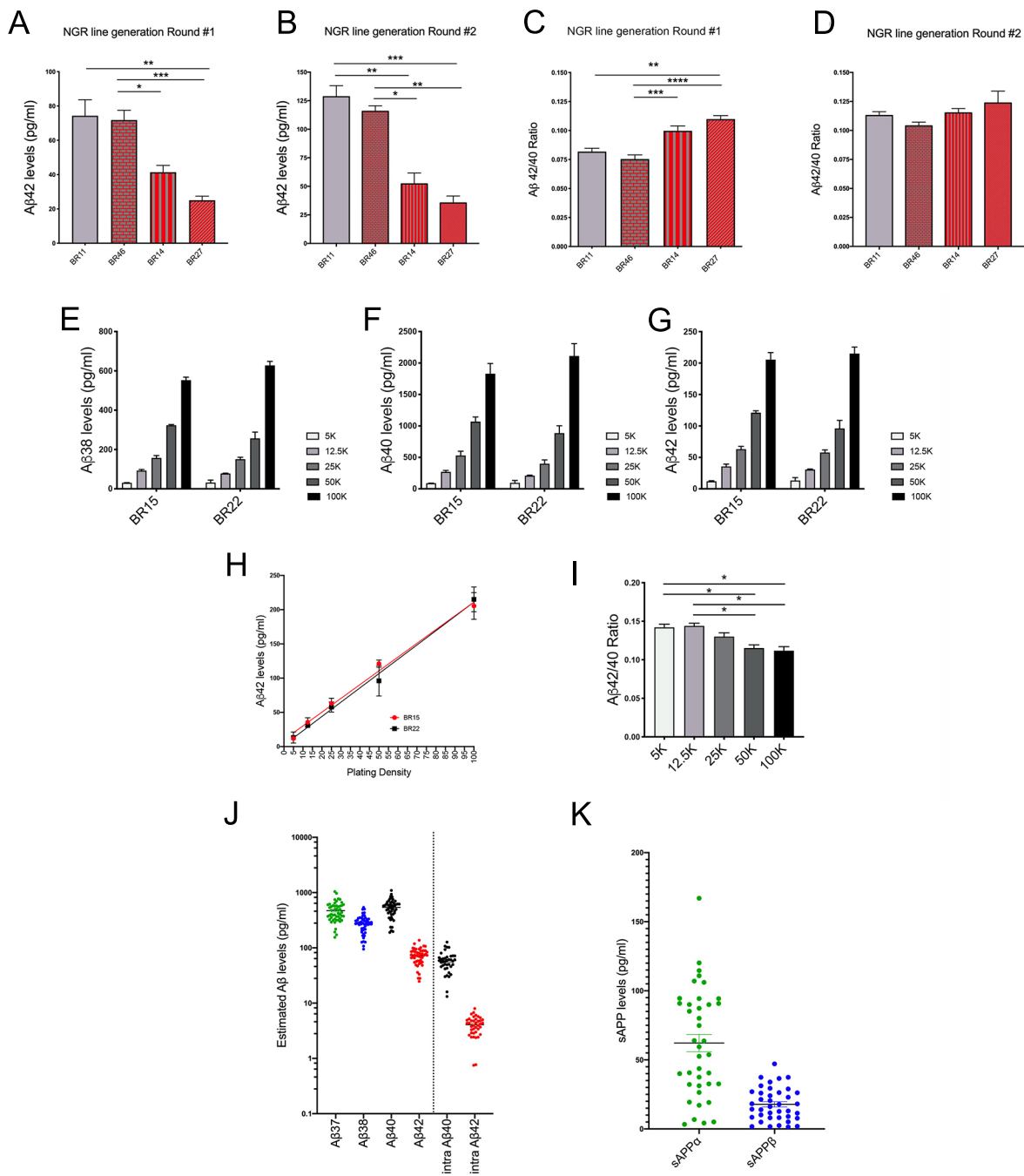


Figure S7.

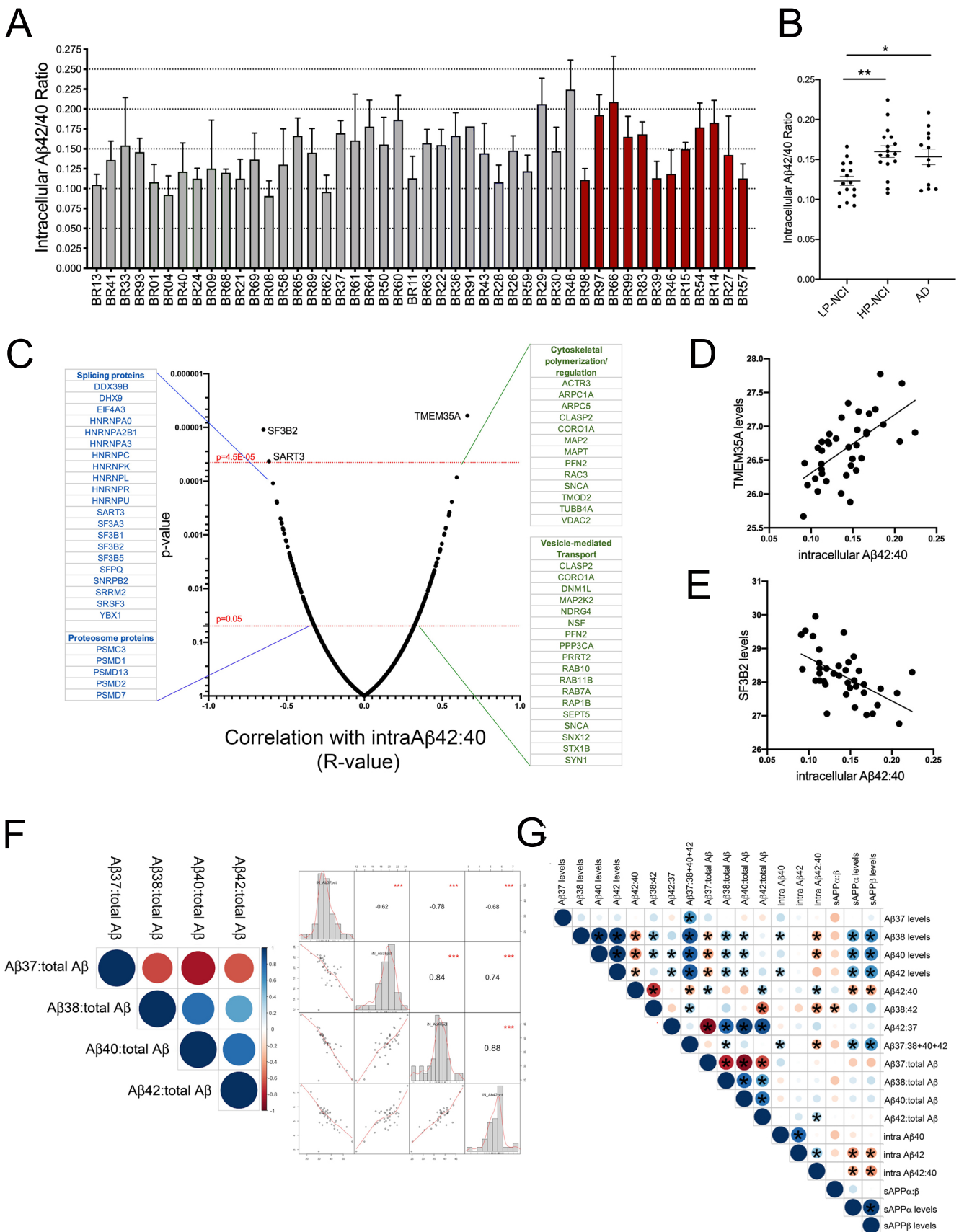


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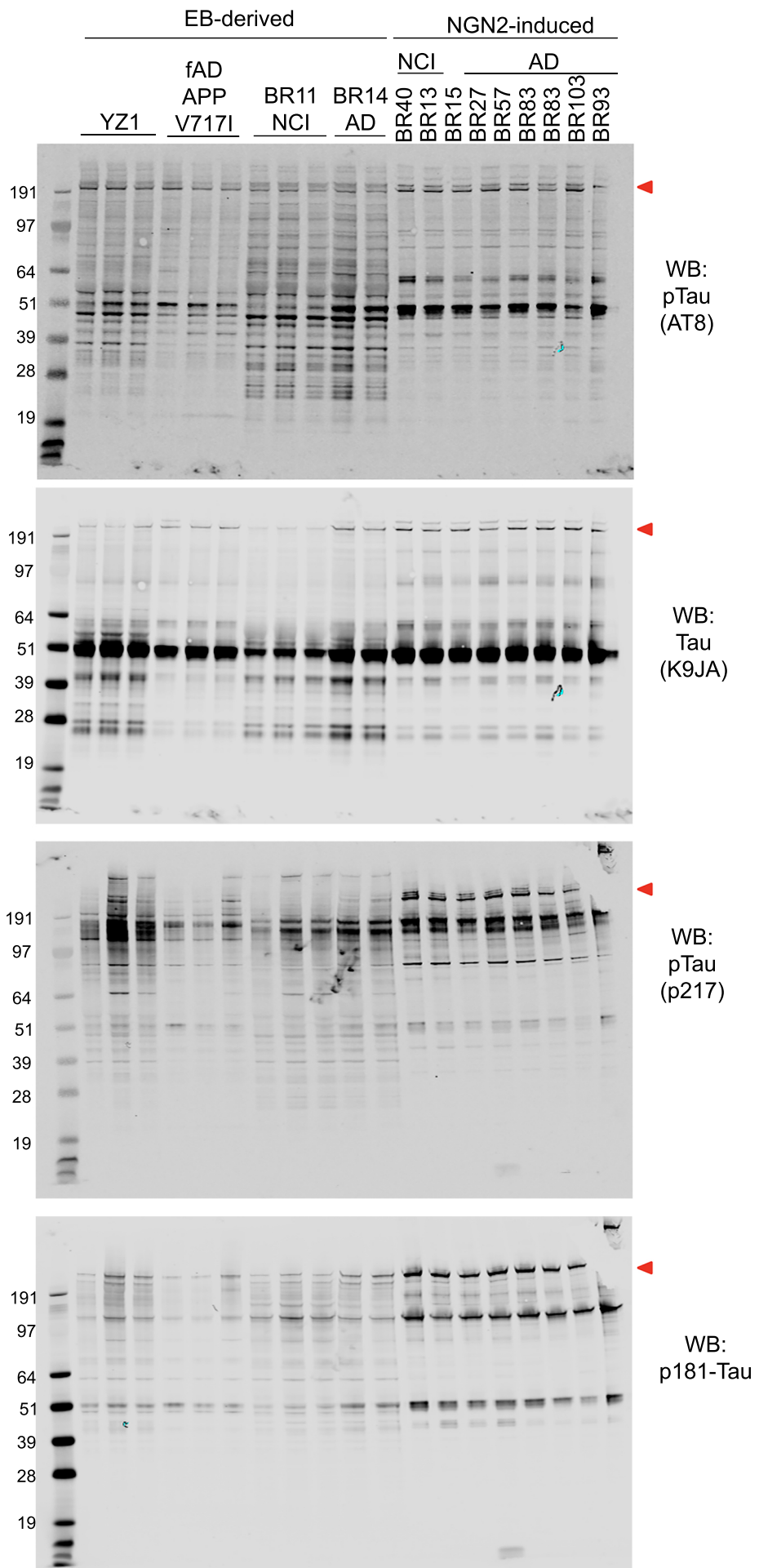


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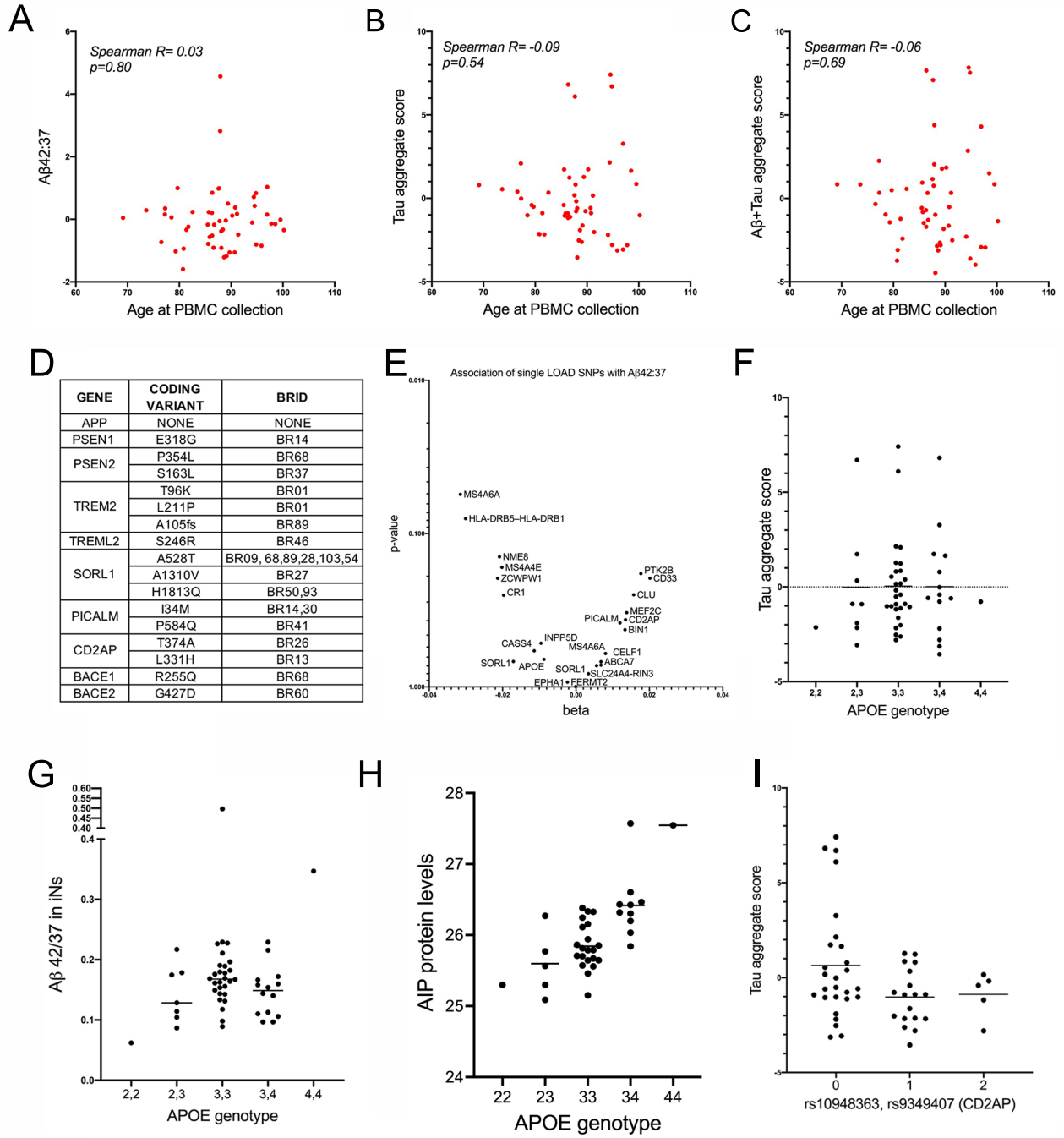


Figure S10.

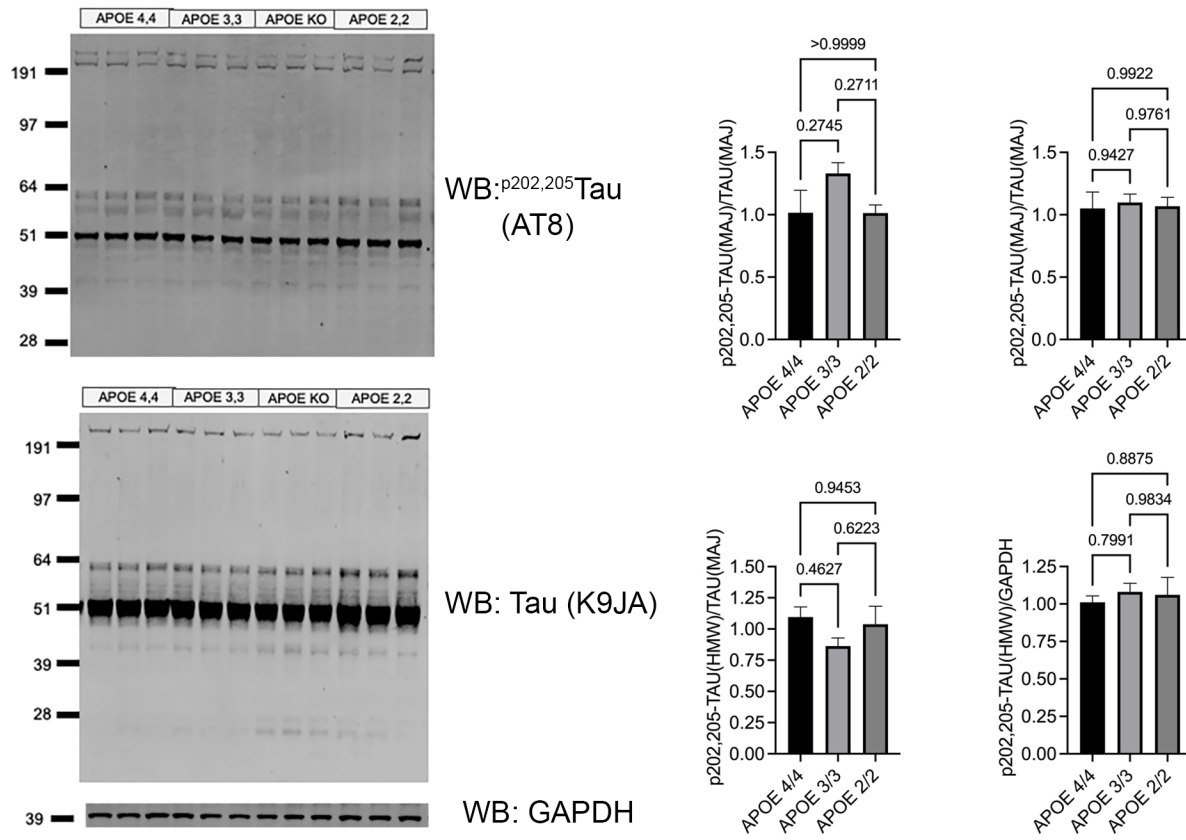


Figure S11.

