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1 **Effects of MiR-137 Genetic Risk Score on Brain Volume and Cortical Measures in Patients with Schizophrenia and Controls**

**Running title:** Effect of MiR-137 PRS on sMRI Measures

Donna Cosgrove PhD,<sup>1</sup> David Omar Mothersill PhD,<sup>1</sup> Laura Whitton MSc,<sup>1</sup> Denise Harold PhD,<sup>2</sup> Sinead Kelly PhD,<sup>3,4</sup> Laurena Holleran PhD,<sup>1</sup> Jessica Holland MSc,<sup>1</sup> Richard Anney PhD,<sup>5,6</sup> The Wellcome Trust Case Control Consortium, Alex Richards PhD,<sup>7</sup> Kiran Mantripragada PhD,<sup>7</sup> Michael Owen PhD,<sup>7</sup> Michael C. O'Donovan PhD,<sup>7</sup> Michael Gill PhD,<sup>5</sup> Aiden Corvin PhD,<sup>5</sup> Derek W Morris PhD,<sup>1</sup> Gary Donohoe PhD.<sup>1</sup>

<sup>1</sup>*The Cognitive Genetics & Cognitive Therapy Group, The School of Psychology and Discipline of Biochemistry, The Centre for Neuroimaging & Cognitive Genomics, National University of Ireland Galway, Ireland*

<sup>2</sup>*School of Biotechnology, Dublin City University, Dublin, Ireland*

<sup>3</sup>*Department of Psychiatry, Beth Israel Deaconess Medical Center, Harvard Medical School*

<sup>4</sup>*Psychiatry Neuroimaging Laboratory, Brigham and Women's Hospital, Harvard Medical School*

<sup>5</sup>*Neuropsychiatric Genetics Research Group, Department of Psychiatry, Institute of Molecular Medicine, Trinity College Dublin, Ireland*

<sup>6</sup>*Institute of Psychological Medicine and Clinical Neurosciences, Cardiff University, UK*

<sup>7</sup>*MRC Centre for Neuropsychiatric Genetics and Genomics, Cardiff University, UK*

**Corresponding Author:**

**Prof. Gary Donohoe**

*The Cognitive Genetics & Cognitive Therapy Group,  
The School of Psychology, National University of Ireland Galway*

**Email:** [gary.donohoe@nuigalway.ie](mailto:gary.donohoe@nuigalway.ie)

**Tel:** +353 91 495122

### Abstract

Multiple genome-wide association studies of schizophrenia have implicated genetic variants within the gene encoding microRNA-137. As risk variants within or regulated by *MIR137* have been implicated in memory performance, we investigated the additive effects of schizophrenia-associated risk variants in genes empirically regulated by *MIR137* on brain regions associated with memory function. A polygenic risk score (PRS) was calculated (at a  $p=0.05$  threshold), using this empirically regulated *MIR137* gene set, to investigate associations between this PRS and structural brain measures. These measures included total brain volume, cortical thickness, cortical surface area, and hippocampal volume, in a sample of 216 individuals consisting of healthy participants ( $n= 171$ ) and patients with psychosis ( $n=45$ ). We did not observe a significant association between *MIR137* PRS and these cortical thickness, surface area or hippocampal volume measures linked to memory function; a significant association between increasing PRS and decreasing total brain volume, independent of diagnosis status ( $R^2 = 0.008$ , Beta =  $-0.09$ ,  $p = 0.029$ ), was observed. This did not survive correction for multiple testing. In conclusion, our study yielded only suggestive evidence that risk variants interacting with *MIR137* impacts on cortical structure.

**Key words:** polygene, GWAS, psychosis, total brain volume

## Introduction

Genome-wide association studies (GWAS) of schizophrenia (SZ) have so far identified 108 regions of DNA encompassing ~350 genes. A strongly polygenic model of SZ, where the overall influence of many genes of small effect combine to increase an individual's predisposition to SZ has been robustly supported (Purcell et al., 2009). No one 'schizophrenia gene' of large effect has been identified, with the number of genes associated with the disorder increasing as GWAS sample size increases. This interplay of SZ risk genes is important to study, given the polygenic nature of the disorder. To characterise the phenotypic effects of multiple risk variants we and others have used polygenic risk scores calculated for gene sets based on either their involvement in a known biological pathway (Hargreaves et al., 2013), or based on evidence of their being regulated by target risk genes, e.g. *ZNF804A* (Nicodemus et al., 2014); *MIR137* (Cosgrove et al., 2017). In these studies, similar effects on cognitive function have been observed by studying either the risk variant individually or the gene network with which it interacts, although the network based analysis can sometimes explain a slightly higher percentage of variation (Cosgrove et al., 2017).

Genetic variants within the gene for microRNA 137 have been among the most significant findings in multiple GWAS (Ripke et al., 2013, The Schizophrenia Psychiatric GWAS Consortium, 2011, Schizophrenia Working Group of the Psychiatric Genomics Consortium, 2014). In the 2011 PGC GWAS, the SNP rs1702294 was the strongest new finding; and in 2014, rs1625579 was the third most highly SZ-associated SNP, both sited in the region of *MIR137* ( $r^2 = 0.99$  with rs1702294). Evidence also suggests that *MIR137* may not uniquely be associated with SZ (Hamshere et al., 2013). There is a strong genetic overlap between SZ and bipolar disorder (Cross-Disorder Group of the Psychiatric Genomics et al., 2013,

Moskvina et al., 2008), even leading to some questions about the diagnostic boundaries between these disorders (Lichtenstein et al., 2009). *In silico* and *in vitro* studies looking at the downstream effects of microRNA-137 have predicted or shown it to impact on the regulation of other genes linked to psychosis (Hill et al., 2014, Collins et al., 2014, Wright et al., 2013). In a study performed to characterise the regulatory effects of miR-137, under-expression of miR-137 led to a general upregulation of many genes, with the opposite shown in overexpression (Olde Loohuis et al., 2017). Risk alleles of four SZ-associated SNPs in the region of *MIR137* (rs1198588, rs1625579, rs2660304 and rs2802535) have been associated with downregulation of miR-137, specific to neuronal cells (Siegert et al., 2015).

MicroRNAs are responsible for the post-translational modification of RNA, altering the quantity of the gene products produced, which has implications for cell function (Yin et al., 2014). *MIR137* functions as a ‘fine-tuning’ agent for synaptic pruning and dendritic arborisation in neural cells and has been associated with, in addition to SZ, altered cognitive function (Kuswanto et al., 2015, Cummings et al., 2013, Green et al., 2013). Patients with SZ experience symptoms of cognitive dysfunction, which have been identified as being one of the largest obstacles to improving SZ patients’ functional outcome (Green et al., 2015). *MIR137* regulates processes that are potentially involved with cognitive dysfunction, in part by acting as a hippocampal gene network node, co-ordinating the expression of genes relating to nervous system function and development (Olde Loohuis et al., 2017). The risk alleles of each of the rs1702294 (C) and rs1625579 (T) SNPs have been linked to poorer scores on neuropsychological tests of memory performance (Cummings et al., 2013, Cosgrove et al., 2017). Furthermore, we previously observed an association between a *MIR137* PRS and memory scores, and between *MIR137* PRS and altered neural connectivity during performance of a fMRI working memory task (Cosgrove et al., 2017). There are conflicting

reports of the effect of the rs1625579 SNP on brain volume (Rose et al., 2014, Lett et al., 2013, Cousijn et al., 2014, Patel et al., 2015); however, to date, the effect of an empirically derived miR-137 regulated gene score on structural brain measures has not been established. Such investigations into potential associations between genetic pathways and brain-based correlates of cognitive phenotypes may assist in elucidating pathophysiological mechanisms that act as contributing factors to these cognitive deficits.

Given the link between *MIR137* and cognition, particularly memory function, the purpose of this study is to investigate the effects of a *MIR137* genetic risk score on measures of cortical thickness, cortical area, hippocampal volume and total brain volume in a sample of healthy participants and patients with psychosis. We hypothesise that participants carrying a higher *MIR137* polygenic risk burden, i.e. higher PRS, will show decreased cortical thickness, cortical area, hippocampal volume and total brain volume in comparison to those with a lower PRS.

## Subjects and Methods

### *Participants*

Participants were recruited in Dublin, patients through outpatient clinics (35 patients with SZ, 8 with schizoaffective disorder and 2 with bipolar disorder) and healthy participants through local media advertising. All participants were Irish, i.e. all four grandparents Irish. All participants were screened for MRI safety criteria, and provided written informed consent in accordance with the guidelines of the local ethics committee (St. James' Hospital). Healthy participants (n=171) age 18-65 were included if they had no history of psychiatric illness, head injury, or drug abuse. Healthy participant sampling at the Dublin site included individuals involved in the Trinity College Biobank project, described in (Rose et al., 2012). All patients (n=45) were chronic, but stable, medicated outpatients, with a confirmed a DSM-IV diagnosis. Demographic and other additional information is presented in **Table 1**.

### *Magnetic Resonance Imaging (MRI)*

Structural MRI sequences were acquired on a Philips Intera Achieva 3T MR system, with whole-brain imaging consisting of a T1-weighted image (180 slices; duration 6 min) using a TFE gradient echo pulse sequence, with a slice thickness of 0.9 mm, and  $230 \times 230$  FOV.

### *FreeSurfer MRI Processing*

Structural MRI images were reconstructed into a three dimensional model of the cortical thickness measurements using FreeSurfer v5.3 which allows for cortical thickness and surface area measurements at numerous locations (vertices) across the surface (Dale et al.,

1999). Processed images were prepared for analysis using the ENIGMA protocol. Briefly, the automated -recon-all function was performed on each scan. Each image underwent motion correction, intensity normalisation, transformation to Talairach space and skull stripping. Mathematical outliers were detected by using R software as per the ENIGMA protocol. In addition to this, each output was visually inspected for T1 quality (artefacts, contrast, resolution, intensity) and to ensure adequate reconstruction. Manual edits to pial surfaces and white matter intensity were carried out where necessary by trained researchers (DC, JH).

Cortical reconstruction, parcellation and segmentation of T1 images were performed using the FreeSurfer 5.3 pipeline, available online. A full description of the FreeSurfer reconstruction process can be found by Dale et al. 1999 (Dale et al., 1999) and Fischl et al. 1999 (Fischl et al., 1999a). The MRI image is 3D rendered into a volume from the MRI into 256 coronal slices (1mm x 1mm x 1mm voxels) and undergoes automated transformation to the Talairach atlas (Talairach and Tournoux, 1988). Intensity normalization is then performed (Sled et al., 1998) to correct non-uniformity in the image due to radiofrequency field. The variation in white matter intensity is then used to estimate the bias field across the entire volume, and the effect of bias field removed by dividing the intensity at each voxel by the estimated bias field at that location. Following this, skull stripping (using a method combining watershed algorithms and deformable surface models) removes the non-brain tissue such as scalp, skull and neck tissue, extracting an initial brain volume (Ségonne et al., 2004). The grey/white matter boundary is estimated by classifying all white matter voxels in an MRI volume, and cerebral white matter segmentation is performed (Fischl and Dale, 2000), deforming this representation of the grey/white boundary outward to the pial surface (Fischl et al., 2001). The WM volume is tiled with a triangular tessellation on each hemisphere to generate an initial surface. The surface deformation follows intensity gradients between white and gray matter, placing the grey/white matter or cerebrospinal fluid borders



at the location where the greatest shift in intensity defines the transition to the other tissue class (Dale and Sereno, 1993, Dale et al., 1999, Fischl and Dale, 2000). The average of the distance from the WM surface to the closest point on the pial surface and from that point back to the closest point on the WM surface gives us the thickness at each location of cortex (Fischl and Dale, 2000). The inflation of the cortical surface is performed so that activity occurring inside sulci may be easily visualized (Fischl et al., 1999b, Fischl et al., 1999a) and each location on the cortical surface is assigned a neuroanatomical label (34 gyral based regions) based on probabilistic information estimated from a manually labelled training set, and also scan-specific measured values (Fischl et al., 2004b, Desikan et al., 2006). Segmentation of the subcortical white matter and deep gray matter volumetric structures (including hippocampus, amygdala, caudate, putamen, ventricles) is performed (Fischl et al., 2002, Fischl et al., 2004a).

Using the ENIGMA protocol for the analysis of mean cortical thickness and surface area data within FreeSurfer ROIs, values for surface area and thickness were extracted. Following this, outliers were identified using R. MATLAB was used to plot cortical surface segmentations directly on each participant's scan and collate snapshots of these into a webpage for visual inspection (the internal surface QC method). The ENIGMA External QC method was performed to check cortical labels and anatomical boundaries. Furthermore, images underwent a thorough visual inspection of each image slice in the coronal, sagittal and axial planes using Freeview.

>>Table 1<<

The automatic segmentation tool Volbrain was used for estimation of hippocampal volume because it is the most accurate method to segment the hippocampus, according to the European Alzheimer's Disease Consortium harmonised hippocampus segmentation protocol, which compares results from software with results from expert manual tracing. This system was used for hippocampal reconstruction as it has been shown that other imaging segmentation software, including FreeSurfer, can overestimate subcortical structures (Manjón and Coupé, 2016). Further information on sMRI processing is available in **Appendix 1**.

### *VolBrain*

The VolBrain pipeline is based on a library of manually labelled templates, constructed from publically available databases: 30 healthy adults, 10 patients with Alzheimer's disease, and 10 infant cases. The pipeline is a set of processing tasks that aims to improve image quality and intensity, and set images into a specific geometric space. Automatic pre-processing of T1-weighted images using the following steps is carried out: denoising and enhancement image quality, inhomogeneity correction, MNI space registration, fine inhomogeneity correction, intensity normalisation, non-local intracranial cavity extraction (white matter, gray matter, and cerebrospinal fluid), tissue classification, non-local hemisphere segmentation (splits brain into five: right and left cerebrum/cerebellum, and brainstem), and non-local subcortical structure segmentation. A more detailed description by Manjón and Coupé (2016) is available.

### *Genotyping*

Genotyping was conducted on DNA samples that were extracted from whole blood or saliva. Samples were genotyped using either Affymetrix 6.0 chip (Santa Clara, CA, USA), as part of the WTCCC2 (Irish Schizophrenia Genomics Consortium and the Wellcome Trust Case Control Consortium, 2012), or Illumina HumanCoreExome chip Illumina (Cardiff sample; San Diego, CA) with full GWAS data available for all participants. Imputation was carried out on these data sets separately using 1000 Genomes Phase I integrated haplotypes (Dec 2013 release) and IMPUTE2 to give ~ 10 million SNPs genome-wide per sample.

### *Polygene Score*

We constructed the *MIR137* PRS based on a set of 1991 genes affected by the up- and downregulation of *MIR137* in human neural progenitor cells (Hill et al., 2014). Of these, 1386 genes that were unambiguously mapped to autosomes were used to generate the PRS (**Supplementary Table 1**). First, the genetic coordinates (+/- 20kb) of these genes were identified (Kent et al., 2002), UCSC hg19 Feb 2009 release. SNPs within these regions were then extracted from our Irish GWAS samples (WTCCC2 and Cardiff; 208,040 and 194,123, respectively). PLINK v1.07 software (Purcell et al., 2007) was used to perform quality control on data from each sample (Affymetrix 6.0 and Illumina HumanCoreExome) separately: SNPs were excluded from further analysis if there was missing genotype data for >10%, Hardy-Weinberg equilibrium  $< 1 \times 10^{-5}$ , or MAF < 1%. Next, the lists of SNPs that passed QC for each sample were joined, providing a SNP list common to each sample (n=185,259 SNPs) regardless of genotyping platform used. This list of common SNPs was used in further analysis. LD clumping was performed separately in each sample using PLINK (-clump,  $r = 0.25$ , distance = 250kb) due to slightly differing LD, giving a list of 2,214 (Cardiff Illumina sample) and 2,235 (WTCCC2 Affymetrix sample) SNPs. Following this,

the PRS was generated for each sample using the LD clump results from the Affymetrix sample. The PRS did not significantly change based on which LD clump results were used: when the PRS was generated using the Illumina sample LD clump values, the results were highly correlated ( $r=0.9$ ,  $p<0.001$ ). The PRS risk threshold defined here was  $p=0.05$ . Previous studies have used multiple PRS thresholds to investigate associations, however, in prior work we have observed a threshold of  $p=0.05$  to be the most informative (Cosgrove et al., 2017). Finally, each participant was given a PRS based number of risk alleles that they carried for each SNP, with alleles weighted by their effect size from the PGC2 GWAS (Schizophrenia Working Group of the Psychiatric Genomics Consortium, 2014) (using the  $-score$  function in PLINK). These effects sizes were taken from a meta-analysis of the PGC2 sample minus all Irish samples to make sure that the discovery and target samples used here were independent.

### *Statistical Analysis*

Age, gender and intracranial volume were used as covariates in all analyses. Whole brain, vertex based analysis was carried out to estimate any effect of PRS on cortical thickness or cortical surface area of the left or right hemispheres. This was performed using the general linear model in QDEC (FreeSurfer), corrected for false discovery rate  $<0.05$ . Analysis of *MIR137* PRS effect on total brain volume and hippocampal volume was performed in SPSS version 23 (IBM Corp, 2015), with moderation analyses carried out using the PROCESS macro for SPSS.

## Results

Participant demographics, brain volume measures and *MIR137* PRS values are displayed in **table 1**. Reflecting the fact that healthy participants were recruited separately from patients rather than as a ‘control’ group, patients were on average older and mostly male. As expected, patients had a significantly higher *MIR137* PRS ( $t_{(214)} = -3.16, p < 0.05$ ). The patient groups were also observed to show lower hippocampal volume ( $t_{(214)} = 2.12, p < 0.05$ ) compared to healthy participants. Brain volume did not show statistically significant differences between cases and controls, although trend level differences for patients to show lower brain volumes were observed ( $t_{(214)} = 1.82, p = 0.071$ , **table 1**).

### *MIR137 PRS & Total Brain Volume*

In the full sample of patients and controls, an effect of PRS on total brain volume was observed ( $R^2 = 0.008$ , Beta = -0.09,  $p = 0.029$ , **table 2**). After correcting for the four sets of analysis carried out however, this finding was no longer significant. As a *post hoc* analysis a moderation analysis was carried out using diagnosis (healthy participants vs. patients with psychosis) as the moderator to determine whether this trend level effect was influenced by diagnosis. After co-varying for the effects of age, gender and intracranial volume, no significant moderating effects of diagnosis on the relationship between *MIR137* PRS and brain volume ( $p = 0.96$ ,  $R^2 = 0.00$ ) were observed, suggesting that the relationship between *MIR137* and brain volume was comparable in both groups. An additional analysis was performed to investigate the effect of medication on this nominally significant finding. Most patients in our sample were medicated, with current medication dose in chlorpromazine equivalent (CPZE) available for 36 out of the 45 patients; healthy participants were not taking any antipsychotic medication. When the analysis was run again including CPZE as well as

age, gender and ICV, the strength of association observed between increasing *MIR137* PRS and lower brain volume decreased ( $R^2 = 0.005$ , Beta = -0.072,  $p = 0.087$ ).

*MIR137 PRS & Cortical Thickness and Surface Area*

No effect of *MIR137* PRS was observed on either cortical thickness or surface area (corrected for false discovery rate <0.05).

*MIR137 PRS & Hippocampal Volume*

No effect of *MIR137* PRS on hippocampal volume, estimated from segmentation results from VolBrain was observed (**Table 2**).

>>Table 2<<

## Discussion

In this study we sought to determine the effect of a SZ-associated, empirically derived, miR-137 regulated gene score on measures of cortical thickness and area, hippocampal volume, and total brain volume. Given the previous reported associations between *MIR137* PRS and cognitive performance, most notably with lower scores on neuropsychological measures of memory function, we hypothesised that a higher PRS would be associated with a decreased cortical thickness and surface area, decreased hippocampal volume and lower total brain volume. No significant association between either cortical thickness or surface area or hippocampal measures and *MIR137* PRS were observed. While association between PRS and total brain volume was nominally significant, when medication (CPZE) was included as an additional covariate in the analysis, this nominally significant association between increasing *MIR137* PRS and decreasing brain volume was no longer significant.

To the best of our knowledge, no study has examined the effect of a *MIR137* PRS score on cortical thickness, shape or volume. Previous imaging studies have investigated the effect of the SZ-associated *MIR137* SNP rs1625579 on brain structure, activation and connectivity and have provided mixed results: this might partly be expected based on the study samples (inclusion of healthy participants only, compared to those looking at patient populations), as well as different regions of interest studied, and the different fMRI tasks used, if any. The first study to investigate the effects of rs1625579 on brain structure by Lett et al. (2013) showed significantly increased ventricle volume in both SZ patients (n=92) and controls (n=121) homozygous for the risk (TT) allele, processed using tools from the FMRIB Software Library (FIRST). In addition, decreased hippocampal volume was observed, but only in patients homozygous for the risk (TT) allele (Lett et al., 2013). Two subsequent structural neuroimaging studies however did not replicate these findings. Cousijn et al. (2014) analysed a large sample of healthy participants (n=1300), also using FIRST. No effects of

rs1625579 genotype on total brain, grey matter, white matter, or hippocampal volumes were observed. Rose et al. (2014) Rose et al. (2014) also looked at the effect of the same *MIR137* rs1625579 risk variant in a voxel-based morphometry study (using SPM) of grey and white matter volume in patients with SZ (n=163) and healthy participants (n=150) and did not observe any significant effects. Similarly, no significant association between genotype and volume of any subcortical regions analysed (using FIRST) was identified in this study, including the hippocampus. The results of the present study are comparable to the results of the larger two of the three studies in terms of the lack of effect of rs1625579 on hippocampal volume. Furthermore, in one of these larger studies, an association between the rs1625579 risk allele and increased ventricle size was reported (Lett et al., 2013). As ventricle size and total brain volume are inversely correlated (Horga et al., 2011), this increased ventricular volume association may be comparable to the link between decreased total brain volume and PRS in the present study. A final structural MRI study reported by Patel et al. (2015) examined the effect of rs1625579 genotype on subcortical and callosal volumes and reported evidence of an association between the risk (G) allele and decreased corpus callosum volume in SZ patients only (n=362) compared to controls (n=490). We did not examine this measure in our sample, although potentially a decrease in corpus callosum volume may contribute to the decrease in overall brain volume reported here.

In this study, we selected only one threshold of polygene score for investigation to limit the multiple testing burden, but is possible that different score thresholds would yield different results. This was not the case in our previous analyses of the cognitive effects of the *MIR137* PRS however, where similar effects were observed across three thresholds analysed ( $p=10^{-5}$ ,  $p=0.05$ ,  $p=0.5$ ), but most strongly at the  $p=0.05$  threshold (Cosgrove et al., 2017), which was the threshold used in this study.



An endophenotypic approach was employed here, i.e. characterising the effects of SZ-associated variants on cortical metrics rather than disease or clinical symptoms (Gottesman and Gould, 2003). The selection of a robust sMRI phenotype to investigate genetic effects is one of the strengths of this study. Total cortical surface area and average cortical thickness are both highly heritable (Panizzon et al., 2009), as is total brain volume (Hulshoff Pol et al., 2002). As surface area and thickness are genetically uncorrelated metrics, these were both investigated (Winkler et al., 2010, Tandon et al., 2016). It has been suggested that cortical thickness is of greater aetiological interest than volume or surface area measures due to the proposed neurodevelopmental mechanisms thought to contribute to SZ and cognitive deficits (Geisler et al., 2015), although no association was observed here between either measure and the *MIR137* PRS. In a meta-analysis comparing cognitive and brain imaging phenotypes, results suggested that SZ variants have greater penetrance on measures of brain structure than other phenotypic measures, such as cognitive performance (Rose and Donohoe, 2013).

The lack of effect of the *MIR137* PRS on any specific cortical region or on the hippocampus and the small effect observed for total brain volume (although not significant after either multiple testing correction, or correction for medication effects) may imply a subtle effect of *MIR137* and its interacting network on more widespread neurological structure, as opposed to being specific to memory-related components. A role of *MIR137* in influencing brain microstructure has previously been established: it has an important role in regulation of target genes linked with neural stem cell proliferation and differentiation during neural development (Mahmoudi and Cairns, 2017). Its role beyond this in terms of how these molecular and cellular effects of *MIR137* itself and the whole *MIR137* network impact brain macrostructure is yet to be defined; however, multiple studies provide evidence that *MIR137* may exert some effect through influence of rs1625579 risk (T) genotype on functional connectivity and neural activation (Mothersill et al., 2013, Liu et al., 2014, Whalley et al., 2012, van Erp et al., 2014).

Due to the extensive regulation of other genes by miRNAs, the dysregulation of even one of these may confer a large polygenic effect. In addition to this, there is evidence that *MIR137* also regulates other genes that harbour SZ-associated variants such as *ZNF804A*, *TCF4*, *CACNA1C*, *CSMD1*, *C10orf26* (Kim et al., 2012, Wright et al., 2013, Guan et al., 2014, Kwon et al., 2013). These convergent pathways linked by *MIR137* may contribute to SZ: previous pathway analysis of miR-137 targets implicated several aspects of nervous system function and development associated with SZ, such as ephrin receptor signalling, axonal guidance signalling and long term potentiation (Wright et al., 2013).

In this study, our sample is comparable, in terms of sample size, with the other studies discussed that investigated the effects of rs1625579 on cortical structures and total brain or hippocampal volumes. Other studies reporting on effects of polygene scores on brain measures include a range of sample sizes. Neilson et al. (2016) reported an association between a SZ polygenic risk score on cortical thinning in patients based on a small sample of 46 patients and 33 controls. Studies such as this with smaller sample sizes report positive associations, however, the replicability of some findings in these smaller study sizes have been questioned (Button et al., 2013). Van der Auwera et al. (2015) observed no effect of a SZ PRS on various structural measures in a large sample of 1,470 healthy participants. Further studies are required to determine if the *MIR137* PRS effects on cortical and hippocampal measures reported here are truly non-significant or whether the uncorrected total brain volume finding may have underestimated an actual effect.

One limitation of this study is that most of our sample was made up of healthy participants. If a potential diagnosis-specific effect was to be identified, a larger patient group would likely be required. As this is the first study to characterise the effect of polygene score on brain structure measures, replication in a different sample is required to further support these findings, preferably in a larger patient population in order to determine whether or not there

are specific disease related consequences of carrying a higher burden of SZ-risk variants in this *MIR137* pathway. In addition, a potential limitation in all imaging studies is that different types of software are used to reconstruct T1 images that can estimate brain volumes differently based on the algorithms used, as well as different QC methodologies. No MDS components were included in the PRS analyses here as the Irish GWAS sample used in the study indicated that the sample was homogeneous. However, it may still be possible that some population stratification effects were present in this sample.

In conclusion, we have not shown evidence of any association between *MIR137* PRS and specific cortical correlates of memory. An association between increasing PRS and decreasing total brain volume however was identified. Further studies with larger sample sizes that include more SZ patients would help clarify the dissociable effects of this microRNA on measures of cognitive function compared to effects in controls. Additional investigations into this miRNA pathway may provide new lines of research to explore in terms of developing a biomarker or therapeutic strategy for SZ.

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### **Conflict of Interest**

The authors declare no conflict of interest specific to this work.

**Web Resources**

UCSC: <http://genome.ucsc.edu>

ENIGMA: <http://enigma.usc.edu/>

FreeSurfer: <http://surfer.nmr.mgh.harvard.edu>

VolBrain: <http://volbrain.upv.es>

R: <https://www.r-project.org/>

Process: <http://processmacro.org>).

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## Tables

**Table 1.** Participant demographics, brain volume measures and *MIR137* genetic risk score (PRS).

|   | Healthy Participants | Patients           | t     | df  | p      |
|---|----------------------|--------------------|-------|-----|--------|
| <b>n</b>  | 171                  | 45                 | -     | -   | -      |
| <b>Age</b>                                      | 28.57 (10.06)        | 41.73 (9.77)       | -7.85 | 214 | <0.001 |
| <b>Female %</b>                                 | 56.14                | 29.55              | 3.32  | 214 | <0.05  |
| <b>Education Years</b>                          | 17.10 (3.16)         | 14.15 (3.95)       | 4.58  | 132 | <0.001 |
| <b><i>MIR137</i> PRS</b>                        | -0.00201 (0.0003)    | -0.00185 (0.0003)  | -3.16 | 214 | <0.05  |
| <b><i>MIR137</i> PRS (standardised z score)</b> | -0.11 (0.98)         | 0.41 (0.99)        | -3.16 | 214 | <0.05  |
| <b>Brain Volume (cm3)</b>                       | 11579.45 (1229.44)   | 11206.31 (1209.52) | 1.82  | 214 | 0.071  |
| <b>Hippocampal Volume (cm3)</b>                 | 7.88 (0.85)          | 7.58 (0.87)        | 2.12  | 214 | <0.05  |

**Table 2.** Effect of *MIR137* PRS (standardised z-score) on hippocampal and total brain volume (age, gender, ICV as covariates).

| Measure                  | B       | SE B  | Beta   | R <sup>2</sup> | p      |
|--------------------------|---------|-------|--------|----------------|--------|
| Hippocampal Volume (cm3) | 0.032   | 0.044 | 0.037  | 0.001          | 0.472  |
| Brain Volume (cm3)       | -111.96 | 50.77 | -0.091 | 0.008          | 0.029* |

## Supplementary File 1 - sMRI Processing and QC

### *FreeSurfer MRI Processing*

Cortical reconstruction, parcellation and segmentation of T1 images were performed using the FreeSurfer 5.3 pipeline, available online (<http://surfer.nmr.mgh.harvard.edu/>). A full description of the FreeSurfer reconstruction process can be found by Dale et al. (1999) and Fischl et al. (1999a). The MRI image is 3D rendered into a volume from the MRI into 256 coronal slices (1mm x 1mm x 1mm voxels) and undergoes automated transformation to the Talairach atlas (Talairach and Tournoux, 1988). Intensity normalization is then performed (Sled et al., 1998) to correct non-uniformity in the image due to radiofrequency field. The variation in white matter intensity is then used to estimate the bias field across the entire volume, and the effect of bias field removed by dividing the intensity at each voxel by the estimated bias field at that location. Following this, skull stripping (using a method combining watershed algorithms and deformable surface models) removes the non-brain tissue such as scalp, skull and neck tissue, extracting an initial brain volume (Ségonne et al., 2004). The grey/white matter boundary is estimated by classifying all white matter voxels in an MRI volume, and cerebral white matter segmentation is performed (Fischl and Dale, 2000), deforming this representation of the grey/white boundary outward to the pial surface (Fischl et al., 2001). The WM volume is tiled with a triangular tessellation on each hemisphere to generate an initial surface. The surface deformation follows intensity gradients between white and gray matter, placing the grey/white matter or cerebrospinal fluid borders at the location where the greatest shift in intensity defines the transition to the other tissue class (Dale and Sereno, 1993, Dale et al., 1999, Fischl and Dale, 2000). The average of the distance from the WM surface to the closest point on the pial surface and from that point back to the closest point on the WM surface gives us the thickness at each location of cortex (Fischl and Dale, 2000). The inflation of the cortical surface is performed so that activity

occurring inside sulci may be easily visualized (Fischl et al., 1999b, Fischl et al., 1999a) and each location on the cortical surface is assigned a neuroanatomical label (34 gyral based regions) based on probabilistic information estimated from a manually labelled training set, and also scan-specific measured values (Fischl et al., 2004b, Desikan et al., 2006). Segmentation of the subcortical white matter and deep gray matter volumetric structures (including hippocampus, amygdala, caudate, putamen, ventricles) is performed (Fischl et al., 2002, Fischl et al., 2004a).

Using the ENIGMA protocol for the analysis of mean cortical thickness and surface area data within FreeSurfer ROIs, values for surface area and thickness were extracted. Following this, outliers were identified using R (<https://www.r-project.org/>). This involves running an R script (<http://enigma.ini.usc.edu/wp-content/uploads/CORTEX/outliers.R>) to identify any images that have outlier values in any of the 73 cortical measures extracted from FreeSurfer. In this script, outliers are defined as any data points that are more than 1.5 times the interquartile range before quartile 1 or after quartile 3 (z scores equivalent to -2.68 or greater than 2.68). Observation of outlier values does not exclude these images from all further analysis automatically, but rather indicates that further inspection to verify image quality is required. Visual inspection is performed on any outlying regions, e.g. where the region may have been poorly segmented by the software. MATLAB was used to plot cortical surface segmentations directly on each participant's scan and collate snapshots of these into a webpage for visual inspection (the internal surface QC method). The ENIGMA External QC method was performed to check cortical labels and anatomical boundaries. Furthermore, images underwent a thorough visual inspection of each image slice in the coronal, sagittal and axial planes using Freeview. The ENIGMA Cortical Quality Control Protocol for QC of images was followed (<http://enigma.ini.usc.edu/protocols/imaging-protocols/>). While a number of outliers were identified in our sample, there were no more than two outliers/regions identified

for any one image. These were inspected visually and were not found to be visually abnormal; thus were kept in the analysis. One or two outlying regions are unlikely to bias a whole-hemisphere vertex based analysis. Based on this protocol, after QC, no scans met the criteria for exclusion.

### *VolBrain*

The VolBrain pipeline is based on a library of manually labelled templates, constructed from publically available databases: 30 healthy adults, 10 patients with Alzheimer's disease, and 10 infant cases. The pipeline is a set of processing tasks that aims to improve image quality and intensity, and set images into a specific geometric space. Automatic pre-processing of T1-weighted images using the following steps is carried out: denoising and enhancement image quality, inhomogeneity correction, MNI space registration, fine inhomogeneity correction, intensity normalisation, non-local intracranial cavity extraction (WM, GM and CSF), tissue classification, non-local hemisphere segmentation (splits brain into five: right and left cerebrum/cerebellum, and brainstem), and non-local subcortical structure segmentation. A more detailed description by Manjón and Coupé (2016) is available.





| Chromosome | Start    | Stop     | Gene     |   |          |          |            |
|------------|----------|----------|----------|---|----------|----------|------------|
| 1          | 1017178  | 1051756  | C1orf159 | 1 | 38181626 | 38230844 | EPHA10     |
| 1          | 1152268  | 1167467  | SDF4     | 1 | 40204497 | 40229606 | PPIE       |
| 1          | 1477033  | 1510282  | SSU72    | 1 | 41326708 | 41328038 | CITED4     |
| 1          | 2115879  | 2144179  | C1orf86  | 1 | 41492851 | 41707835 | SCMH1      |
| 1          | 6475272  | 6484744  | HES2     | 1 | 41827308 | 41849283 | FOXO6      |
| 1          | 9789059  | 9884570  | CLSTN1   | 1 | 43148040 | 43168044 | YBX1       |
| 1          | 9789059  | 9884570  | CLSTN1   | 1 | 44398972 | 44402932 | ARTN       |
| 1          | 9982148  | 10003480 | LZIC     | 1 | 44412458 | 44433714 | IPO13      |
| 1          | 11734517 | 11751698 | MAD2L2   | 1 | 44435633 | 44439063 | DPH2       |
| 1          | 15479008 | 15546994 | TMEM51   | 1 | 46640729 | 46651654 | TSPAN1     |
| 1          | 17345197 | 17380685 | SDHB     | 1 | 46769304 | 46782468 | UQCRH      |
| 1          | 19197904 | 19229313 | ALDH4A1  | 1 | 47100691 | 47134119 | ATPAF1     |
| 1          | 20439123 | 20446079 | PLA2G2D  | 1 | 47799449 | 47844531 | CMPK1      |
| 1          | 20808864 | 20812748 | CAMK2N1  | 1 | 48761024 | 48937896 | SPATA6     |
| 1          | 21543720 | 21672054 | ECE1     | 1 | 50906915 | 51425956 | FAF1       |
| 1          | 22889984 | 22930107 | EPHA8    | 1 | 51434347 | 51440329 | CDKN2C     |
| 1          | 23037243 | 23241843 | EPHB2    | 1 | 52254844 | 52344629 | NRD1       |
| 1          | 23635933 | 23671163 | HNRNPR   | 1 | 52497757 | 52499492 | KTI12      |
| 1          | 23685921 | 23696377 | ZNF436   | 1 | 52870199 | 52884012 | PRPF38A    |
| 1          | 24969574 | 24999792 | SRRM1    | 1 | 54411979 | 54433861 | LRRC42     |
| 1          | 25548747 | 25559033 | SYF2     | 1 | 58881032 | 59012489 | OMA1       |
| 1          | 25943939 | 26111278 | MAN1C1   | 1 | 59246443 | 59249805 | JUN        |
| 1          | 28099674 | 28150983 | STX12    | 1 | 62146698 | 62191115 | TM2D1      |
| 1          | 28526769 | 28559562 | DNAJC8   | 1 | 63249757 | 63330961 | ATG4C      |
| 1          | 32372002 | 32404008 | PTP4A2   | 1 | 64058927 | 64125936 | PGM1       |
| 1          | 33116729 | 33151832 | RBBP4    | 1 | 65298886 | 65432613 | JAK1       |
| 1          | 33473521 | 33502532 | AK2      | 1 | 68150840 | 68154041 | GADD45A    |
| 1          | 36621731 | 36646470 | MAP7D1   | 1 | 68894487 | 68915662 | RPE65      |
| 1          | 38022500 | 38032478 | DNALI1   | 1 | 77333106 | 77533243 | ST6GALNAC5 |
|            |          |          |          | 1 | 84963986 | 84972282 | GNG5       |

|   |           |           |          |   |           |           |         |
|---|-----------|-----------|----------|---|-----------|-----------|---------|
| 1 | 89571795  | 89591862  | GBP2     | 1 | 150547007 | 150552234 | MCL1    |
| 1 | 90286553  | 90402011  | LRR8D    | 1 | 151009009 | 151020096 | BNIP1   |
| 1 | 90460658  | 90494121  | ZNF326   | 1 | 151104141 | 151119166 | SEMA6C  |
| 1 | 94352570  | 94375174  | GCLM     | 1 | 152004962 | 152009531 | S100A11 |
| 1 | 95448259  | 95538532  | ALG14    | 1 | 153516075 | 153518302 | S100A4  |
| 1 | 95448259  | 95538532  | ALG14    | 1 | 153516075 | 153518302 | S100A4  |
| 1 | 97187141  | 97280625  | PTBP2    | 1 | 153954073 | 153958873 | RAB13   |
| 1 | 97543279  | 98386635  | DPYD     | 1 | 155023728 | 155035272 | ADAM15  |
| 1 | 100174186 | 100232206 | FRRS1    | 1 | 155158280 | 155162788 | MUC1    |
| 1 | 101455159 | 101491385 | DPH5     | 1 | 155216976 | 155225294 | FAM189B |
| 1 | 103342003 | 103574072 | COL11A1  | 1 | 155278519 | 155290477 | FDPS    |
| 1 | 108113762 | 108507565 | VAV3     | 1 | 155629213 | 155658843 | YY1AP1  |
| 1 | 109834967 | 109849683 | MYBPHL   | 1 | 155657673 | 155708821 | DAP3    |
| 1 | 109941633 | 109969128 | PSMA5    | 1 | 155978819 | 155990778 | SSR2    |
| 1 | 109941633 | 109969128 | PSMA5    | 1 | 156002925 | 156023633 | UBQLN4  |
| 1 | 110276534 | 110283680 | GSTM3    | 1 | 156041784 | 156051809 | MEX3A   |
| 1 | 111682229 | 111727744 | CEPT1    | 1 | 156182759 | 156209888 | PMF1    |
| 1 | 113252596 | 113257970 | PPM1J    | 1 | 159997442 | 160001803 | PIGM    |
| 1 | 114304434 | 114355090 | RSBN1    | 1 | 160313043 | 160328762 | NCSTN   |
| 1 | 114935379 | 115053801 | TRIM33   | 1 | 161007398 | 161008907 | TSTD1   |
| 1 | 117117000 | 117210397 | IGSF3    | 1 | 161141080 | 161147778 | B4GALT3 |
| 1 | 117452669 | 117532992 | PTGFRN   | 1 | 161284146 | 161334561 | SDHC    |
| 1 | 120254399 | 120286869 | PHGDH    | 1 | 161511529 | 161520433 | FCGR3A  |
| 1 | 145176359 | 145286290 | NOTCH2NL | 1 | 161511529 | 161520433 | FCGR3A  |
| 1 | 145176359 | 145286290 | NOTCH2NL | 1 | 161719538 | 161726972 | DUSP12  |
| 1 | 145524689 | 145543888 | ITGA10   | 1 | 161952962 | 161994192 | OLFML2B |
| 1 | 148003011 | 148025885 | NBPF14   | 1 | 162602208 | 162756429 | DDR2    |
| 1 | 149874850 | 149889454 | SV2A     | 1 | 165631429 | 165667920 | ALDH9A1 |
| 1 | 150237779 | 150241629 | APH1A    | 1 | 165693508 | 165738179 | TMCO1   |
| 1 | 150266242 | 150281434 | MRPS21   | 1 | 165796712 | 165880875 | UCK2    |

|   |           |           |          |   |           |           |          |
|---|-----------|-----------|----------|---|-----------|-----------|----------|
| 1 | 168148151 | 168171372 | TIPRL    | 1 | 229406789 | 229441661 | RAB4A    |
| 1 | 169101238 | 169337206 | NME7     | 1 | 230972845 | 231005355 | C1orf198 |
| 1 | 171669276 | 171711399 | VAMP4    | 1 | 231041967 | 231114638 | TTC13    |
| 1 | 171810598 | 172387626 | DNM3     | 1 | 233119835 | 233431479 | PCNXL2   |
| 1 | 173793699 | 173827702 | DARS2    | 1 | 233749730 | 233808278 | KCNK1    |
| 1 | 175913947 | 176176406 | RFWD2    | 1 | 236681494 | 236716301 | LGALS8   |
| 1 | 179851157 | 179889232 | TOR1AIP1 | 1 | 236712285 | 236767861 | HEATR1   |
| 1 | 179851157 | 179889232 | TOR1AIP1 | 1 | 242158772 | 242164650 | MAP1LC3C |
| 1 | 179851157 | 179889232 | TOR1AIP1 | 1 | 243651515 | 244014401 | AKT3     |
| 1 | 182613016 | 182653522 | RGS8     | 1 | 246703843 | 246729585 | TFB2M    |
| 1 | 192981476 | 193029257 | UCHL5    | 1 | 246703843 | 246729585 | TFB2M    |
| 1 | 193028532 | 193060927 | TROVE2   | 1 | 247002380 | 247094746 | AHCTF1   |
| 1 | 200374055 | 200379206 | ZNF281   | 1 | 249144183 | 249153335 | ZNF692   |
| 1 | 201434587 | 201438319 | PHLDA3   | 2 | 279541    | 289022    | FAM150B  |
| 1 | 201452638 | 201476407 | CSRP1    | 2 | 1635639   | 1748311   | PXDN     |
| 1 | 202847390 | 202858405 | RABIF    | 2 | 3592655   | 3605977   | RNASEH1  |
| 1 | 203096813 | 203136553 | ADORA1   | 2 | 3622833   | 3628529   | RPS7     |
| 1 | 204100170 | 204121327 | ETNK2    | 2 | 7017776   | 7038390   | RSAD2    |
| 1 | 205055250 | 205091170 | RBBP5    | 2 | 10170756  | 10194983  | KLF11    |
| 1 | 205350486 | 205391234 | LEMD1    | 2 | 11319874  | 11484731  | ROCK2    |
| 1 | 211499829 | 211548423 | TRAF5    | 2 | 18735969  | 18741979  | RDH14    |
| 1 | 212738656 | 212794139 | ATF3     | 2 | 18735969  | 18741979  | RDH14    |
| 1 | 212899475 | 212965159 | NSL1     | 2 | 24714899  | 24993591  | NCOA1    |
| 1 | 216676568 | 217311117 | ESRRG    | 2 | 25962233  | 26101332  | ASXL2    |
| 1 | 220701548 | 220837819 | MARK1    | 2 | 26467596  | 26513353  | HADHB    |
| 1 | 222791424 | 222841371 | MIA3     | 2 | 26915561  | 26954086  | KCNK3    |
| 1 | 224301769 | 224349769 | FBXO28   | 2 | 27193505  | 27250107  | MAPRE3   |
| 1 | 225997777 | 226033284 | EPHX1    | 2 | 27587199  | 27593344  | EIF2B4   |
| 1 | 226250388 | 226259723 | H3F3A    | 2 | 27604046  | 27632570  | PPM1G    |
| 1 | 226250388 | 226259723 | H3F3A    | 2 | 28974594  | 29025826  | PPP1CB   |

|   |          |          |          |   |           |           |         |
|---|----------|----------|----------|---|-----------|-----------|---------|
| 2 | 29204144 | 29275116 | FAM179A  | 2 | 101008302 | 101034150 | CHST10  |
| 2 | 29415620 | 30144497 | ALK      | 2 | 101887661 | 101925198 | RNF149  |
| 2 | 30454377 | 30482919 | LBH      | 2 | 106361500 | 106510750 | NCK2    |
| 2 | 32581715 | 32843986 | BIRC6    | 2 | 112973419 | 113012684 | ZC3H8   |
| 2 | 33808707 | 33824382 | FAM98A   | 2 | 120517187 | 120742516 | PTPN4   |
| 2 | 36583350 | 36778298 | CRIM1    | 2 | 128056225 | 128100825 | MAP3K2  |
| 2 | 38522007 | 38604452 | ATL2     | 2 | 128603820 | 128615749 | POLR2D  |
| 2 | 42275141 | 42285688 | PKDCC    | 2 | 131594469 | 131804846 | ARHGEF4 |
| 2 | 44395964 | 44471590 | PPM1B    | 2 | 131805429 | 131851053 | FAM168B |
| 2 | 44395964 | 44471590 | PPM1B    | 2 | 136289016 | 136482859 | R3HDM1  |
| 2 | 46738966 | 46769571 | ATP6V1E2 | 2 | 136871899 | 136875745 | CXCR4   |
| 2 | 46808393 | 46844271 | PIGF     | 2 | 149894961 | 150071796 | LYPD6B  |
| 2 | 46844305 | 46852901 | CRIP1    | 2 | 149894961 | 150071796 | LYPD6B  |
| 2 | 53897097 | 54014166 | ASB3     | 2 | 152657460 | 152685029 | ARL5A   |
| 2 | 56093077 | 56151318 | EFEMP1   | 2 | 175612300 | 175629220 | CHRNA1  |
| 2 | 62423242 | 62451886 | B3GNT2   | 2 | 175612300 | 175629220 | CHRNA1  |
| 2 | 64119260 | 64246546 | VPS54    | 2 | 175664022 | 175870691 | CHN1    |
| 2 | 64319766 | 64371625 | PELI1    | 2 | 176040966 | 176046510 | ATP5G3  |
| 2 | 65215559 | 65251019 | SLC1A4   | 2 | 178977129 | 178994403 | RBM45   |
| 2 | 68694671 | 68839381 | APLF     | 2 | 183697982 | 183731518 | FRZB    |
| 2 | 74699065 | 74699962 | MRPL53   | 2 | 190611366 | 190628040 | OSGEPL1 |
| 2 | 75059762 | 75120501 | HK2      | 2 | 198351288 | 198365018 | HSPD1   |
| 2 | 86426458 | 86440933 | MRPL35   | 2 | 198364701 | 198368207 | HSPE1   |
| 2 | 86441096 | 86565226 | REEP1    | 2 | 198591583 | 198651056 | BOLL    |
| 2 | 96068419 | 96082377 | FAHD2A   | 2 | 201980857 | 202037431 | CFLAR   |
| 2 | 96778603 | 96782301 | ADRA2B   | 2 | 201980857 | 202037431 | CFLAR   |
| 2 | 96931864 | 96939937 | CIAO1    | 2 | 202316372 | 202359521 | STRADB  |
| 2 | 97426619 | 97477648 | CNNM4    | 2 | 203745303 | 203776969 | WDR12   |
| 2 | 97749300 | 97760623 | FAHD2B   | 2 | 206547164 | 206662877 | NRP2    |
| 2 | 99061301 | 99207516 | INPP4A   | 2 | 209100931 | 209120498 | IDH1    |

|   |           |           |          |   |          |          |          |
|---|-----------|-----------|----------|---|----------|----------|----------|
| 2 | 210288713 | 210598862 | MAP2     | 3 | 33191517 | 33260727 | SUSD5    |
| 2 | 217536808 | 217560292 | IGFBP5   | 3 | 39448184 | 39454053 | RPSA     |
| 2 | 219135095 | 219211536 | PNKD     | 3 | 40498763 | 40503883 | RPL14    |
| 2 | 220074468 | 220083732 | ABCB6    | 3 | 42055274 | 42267402 | TRAK1    |
| 2 | 220084082 | 220094407 | ATG9A    | 3 | 42530771 | 42579085 | VIPR1    |
| 2 | 220110172 | 220115079 | STK16    | 3 | 42642127 | 42690253 | NKTR     |
| 2 | 220403649 | 220408507 | CHPF     | 3 | 43407798 | 43663580 | ANO10    |
| 2 | 220408365 | 220415337 | TMEM198  | 3 | 43732355 | 43764237 | ABHD5    |
| 2 | 220492272 | 220506722 | SLC4A3   | 3 | 44666491 | 44689983 | ZNF197   |
| 2 | 227596013 | 227664565 | IRS1     | 3 | 45123746 | 45187934 | CDCP1    |
| 2 | 227596013 | 227664565 | IRS1     | 3 | 46477476 | 46506618 | LTF      |
| 2 | 228336833 | 228425958 | AGFG1    | 3 | 47422363 | 47454951 | PTPN23   |
| 2 | 230899670 | 230933735 | SLC16A14 | 3 | 48509177 | 48542279 | SHISA5   |
| 2 | 233412759 | 233415246 | TIGD1    | 3 | 48725416 | 48754731 | IP6K2    |
| 2 | 234160197 | 234204340 | ATG16L1  | 3 | 48894336 | 48936446 | SLC25A20 |
| 2 | 234263129 | 234380764 | DGKD     | 3 | 49057888 | 49060948 | NDUFAF3  |
| 2 | 238875567 | 238951443 | UBE2F    | 3 | 49314557 | 49377556 | USP4     |
| 2 | 241499451 | 241503451 | DUSP28   | 3 | 49761708 | 49823993 | IP6K1    |
| 2 | 242254703 | 242293462 | SEPT2    | 3 | 50229023 | 50235149 | GNAT1    |
| 3 | 4402809   | 4508986   | SUMF1    | 3 | 50362321 | 50365688 | TUSC2    |
| 3 | 5229339   | 5261670   | EDEM1    | 3 | 50388245 | 50391520 | CYB561D2 |
| 3 | 9691097   | 9744098   | MTMR14   | 3 | 52002506 | 52008666 | ABHD14B  |
| 3 | 9821628   | 9834715   | TADA3    | 3 | 52728480 | 52740119 | GLT8D1   |
| 3 | 12194548  | 12200871  | TIMP4    | 3 | 57741928 | 57915617 | SLMAP    |
| 3 | 15422762  | 15469074  | METTL6   | 3 | 58223213 | 58280483 | ABHD6    |
| 3 | 15491620  | 15563297  | COLQ     | 3 | 58413337 | 58419599 | PDHB     |
| 3 | 16357332  | 16555242  | RFTN1    | 3 | 58477803 | 58488107 | KCTD6    |
| 3 | 20202065  | 20227744  | SGOL1    | 3 | 58549821 | 58613357 | FAM107A  |
| 3 | 32023246  | 32033248  | ZNF860   | 3 | 73431562 | 73674092 | PDZRN3   |
| 3 | 32433143  | 32496353  | CMTM7    | 3 | 88101080 | 88199036 | CGGBP1   |

|   |           |           |          |   |           |           |              |
|---|-----------|-----------|----------|---|-----------|-----------|--------------|
| 3 | 99979641  | 100044116 | TBC1D23  | 3 | 165490672 | 165555280 | BCHE         |
| 3 | 101399914 | 101405584 | RPL24    | 3 | 169490599 | 169507524 | MYNN         |
| 3 | 119147787 | 119182549 | TMEM39A  | 3 | 170606184 | 170626446 | EIF5A2       |
| 3 | 121488588 | 121553946 | IQCB1    | 3 | 170780272 | 171178217 | TNIK         |
| 3 | 121488588 | 121553946 | IQCB1    | 3 | 180630076 | 180700561 | FXR1         |
| 3 | 122130680 | 122134902 | WDR5B    | 3 | 181429692 | 181432244 | SOX2         |
| 3 | 122513881 | 122600006 | DIRC2    | 3 | 183960097 | 183967333 | ALG3         |
| 3 | 124449193 | 124468140 | UMPS     | 3 | 190231820 | 190378876 | IL1RAP       |
| 3 | 124449193 | 124468140 | UMPS     | 3 | 194075956 | 194090492 | LRRC15       |
| 3 | 124944493 | 125094218 | ZNF148   | 3 | 196281004 | 196295647 | WDR53        |
| 3 | 125725180 | 125820418 | SLC41A3  | 3 | 196662253 | 196669484 | NCBP2        |
| 3 | 127407885 | 127542113 | MGLL     | 3 | 196769411 | 197026191 | DLG1         |
| 3 | 128338793 | 128369739 | RPN1     | 3 | 197476404 | 197511337 | FYTTD1       |
| 3 | 128806392 | 128841013 | RAB43    | 4 | 666205    | 668147    | ATP5I        |
| 3 | 128886638 | 128902830 | CNBP     | 4 | 669697    | 675842    | MYL5         |
| 3 | 128886638 | 128902830 | CNBP     | 4 | 1004692   | 1020706   | FGFRL1       |
| 3 | 131252393 | 131759172 | CPNE4    | 4 | 1004692   | 1020706   | FGFRL1       |
| 3 | 131252393 | 131759172 | CPNE4    | 4 | 1283622   | 1333945   | MAEA         |
| 3 | 133292414 | 133309138 | CDV3     | 4 | 2043700   | 2045717   | C4orf48      |
| 3 | 133292414 | 133309138 | CDV3     | 4 | 6641798   | 6644492   | MRFAP1       |
| 3 | 133543059 | 133614711 | RAB6B    | 4 | 6641798   | 6644492   | MRFAP1       |
| 3 | 134074167 | 134094341 | AMOTL2   | 4 | 8951457   | 8952147   | LOC650293    |
| 3 | 137906095 | 138017251 | ARMC8    | 4 | 9400847   | 9405311   | LOC100133128 |
| 3 | 139062841 | 139075908 | MRPS22   | 4 | 9400847   | 9405311   | LOC100133128 |
| 3 | 142025429 | 142166924 | XRN1     | 4 | 17578907  | 17609610  | LAP3         |
| 3 | 142536682 | 142608065 | PCOLCE2  | 4 | 20702016  | 20730000  | PACRGL       |
| 3 | 143690620 | 143711230 | C3orf58  | 4 | 25378828  | 25420140  | ANAPC4       |
| 3 | 151044076 | 151047357 | P2RY13   | 4 | 39046288  | 39127873  | KLHL5        |
| 3 | 157813780 | 157823972 | SHOX2    | 4 | 48832579  | 48863854  | OCIAD1       |
| 3 | 160801651 | 160823180 | B3GALNT1 | 4 | 56294048  | 56413096  | CLOCK        |

|   |           |           |         |   |           |           |         |
|---|-----------|-----------|---------|---|-----------|-----------|---------|
| 4 | 57276662  | 57327554  | PAICS   | 4 | 169137422 | 169239978 | DDX60   |
| 4 | 57514134  | 57547894  | HOPX    | 4 | 169418195 | 169849628 | PALLD   |
| 4 | 71570627  | 71674356  | RUFY3   | 4 | 177241070 | 177253416 | SPCS3   |
| 4 | 76831788  | 76862186  | NAAA    | 4 | 184426200 | 184433442 | ING2    |
| 4 | 76871044  | 76912135  | SDAD1   | 4 | 189060578 | 189068669 | TRIML1  |
| 4 | 76942249  | 76944709  | CXCL10  | 4 | 189060578 | 189068669 | TRIML1  |
| 4 | 77035792  | 77069688  | NUP54   | 5 | 204855    | 218353    | CCDC127 |
| 4 | 83274447  | 83295169  | HNRNPD  | 5 | 7859252   | 7869170   | FASTKD3 |
| 4 | 83550670  | 83720030  | SCD5    | 5 | 10225599  | 10250165  | FAM173B |
| 4 | 83739794  | 83812439  | SEC31A  | 5 | 16661996  | 16936405  | MYO10   |
| 4 | 88928779  | 88998951  | PKD2    | 5 | 31532353  | 31555185  | C5orf22 |
| 4 | 89299818  | 89364269  | HERC6   | 5 | 32227091  | 32313134  | MTMR12  |
| 4 | 99391498  | 99579832  | TSPAN5  | 5 | 32354436  | 32444864  | ZFR     |
| 4 | 100737937 | 100791367 | DAPP1   | 5 | 34915800  | 34925807  | BRIX1   |
| 4 | 110736646 | 110745913 | GAR1    | 5 | 37291715  | 37371248  | NUP155  |
| 4 | 110736646 | 110745913 | GAR1    | 5 | 40831410  | 40835407  | RPL37   |
| 4 | 113434652 | 113437348 | NEUROG2 | 5 | 52285136  | 52390629  | ITGA2   |
| 4 | 114372168 | 114683689 | CAMK2D  | 5 | 64885487  | 64920207  | TRIM23  |
| 4 | 114372168 | 114683689 | CAMK2D  | 5 | 67511564  | 67597669  | PIK3R1  |
| 4 | 122745464 | 122791672 | BBS7    | 5 | 69321058  | 69338955  | SERF1B  |
| 4 | 122745464 | 122791672 | BBS7    | 5 | 69321058  | 69338955  | SERF1B  |
| 4 | 128982401 | 129144106 | LARP1B  | 5 | 70883095  | 70954553  | MCCC2   |
| 4 | 140374941 | 140397090 | RAB33B  | 5 | 71515216  | 71616104  | MRPS27  |
| 4 | 145567128 | 145662562 | HHIP    | 5 | 72794230  | 72801468  | BTF3    |
| 4 | 146540520 | 146581207 | MMAA    | 5 | 76248660  | 76265319  | CRHBP   |
| 4 | 150999406 | 151178629 | DCLK2   | 5 | 78985639  | 79096069  | CMYA5   |
| 4 | 151185791 | 151936899 | LRBA    | 5 | 79922025  | 79950820  | DHFR    |
| 4 | 154265781 | 154336267 | MND1    | 5 | 79922025  | 79950820  | DHFR    |
| 4 | 157997257 | 158093271 | GLRB    | 5 | 79950447  | 80172654  | MSH3    |
| 4 | 159587807 | 159593427 | C4orf46 | 5 | 80597382  | 80608986  | ZCCHC9  |



|   |           |           |         |   |           |           |          |
|---|-----------|-----------|---------|---|-----------|-----------|----------|
| 5 | 86687290  | 86708870  | CCNH    | 5 | 147258254 | 147261776 | SCGB3A2  |
| 5 | 95997721  | 96110407  | CAST    | 5 | 148737550 | 148749241 | PCYOX1L  |
| 5 | 102201507 | 102366829 | PAM     | 5 | 149340280 | 149366983 | SLC26A2  |
| 5 | 102594422 | 102614381 | C5orf30 | 5 | 150040383 | 150058950 | MYOZ3    |
| 5 | 110427850 | 110466220 | WDR36   | 5 | 150480247 | 150537463 | ANXA6    |
| 5 | 112212061 | 112258359 | REEP5   | 5 | 150560593 | 150603674 | CCDC69   |
| 5 | 114602865 | 114632478 | CCDC112 | 5 | 151040637 | 151066635 | SPARC    |
| 5 | 121398870 | 121414226 | LOX     | 5 | 156512823 | 156536268 | HAVCR2   |
| 5 | 121647435 | 121799814 | SNCAIP  | 5 | 167719045 | 167899328 | WWC1     |
| 5 | 122359058 | 122372445 | PPIC    | 5 | 169780471 | 170163656 | KCNIP1   |
| 5 | 125936587 | 125962964 | PHAX    | 5 | 171288533 | 171433897 | FBXW11   |
| 5 | 131528279 | 131563576 | P4HA2   | 5 | 172261203 | 172379708 | ERGIC1   |
| 5 | 132387642 | 132440729 | HSPA4   | 5 | 172410743 | 172461920 | ATP6V0E1 |
| 5 | 137273618 | 137387670 | FAM13B  | 5 | 172410743 | 172461920 | ATP6V0E1 |
| 5 | 137475435 | 137514378 | BRD8    | 5 | 175810920 | 175815783 | NOP16    |
| 5 | 138089055 | 138270743 | CTNNA1  | 5 | 176732481 | 176741116 | MXD3     |
| 5 | 138282389 | 138534085 | SIL1    | 5 | 176784684 | 176799619 | RGS14    |
| 5 | 138609421 | 138667386 | MATR3   | 5 | 176883593 | 176900714 | DBN1     |
| 5 | 138745872 | 138780191 | DNAJC18 | 5 | 176910375 | 176924626 | PDLIM7   |
| 5 | 140018992 | 140025009 | TMCO6   | 5 | 177631488 | 177638204 | HNRNPAB  |
| 5 | 140018992 | 140025009 | TMCO6   | 5 | 177631488 | 177638204 | HNRNPAB  |
| 5 | 140024928 | 140027390 | NDUFA2  | 5 | 179124999 | 179158662 | CANX     |
| 5 | 140743709 | 140892566 | PCDHGA5 | 5 | 179224577 | 179233972 | MGAT4B   |
| 5 | 140855549 | 140892566 | PCDHGC3 | 5 | 180217521 | 180237959 | MGAT1    |
| 5 | 140855549 | 140892566 | PCDHGC3 | 5 | 180683353 | 180688181 | TRIM52   |
| 5 | 141032948 | 141061820 | ARAP3   | 6 | 485118    | 693161    | EXOC2    |
| 5 | 145492569 | 145562314 | LARS    | 6 | 3000047   | 3020017   | NQO2     |
| 5 | 145826853 | 145891091 | TCERG1  | 6 | 7281263   | 7313561   | SSR1     |
| 5 | 146770351 | 146889639 | DPYSL3  | 6 | 8073573   | 8102848   | EEF1E1   |
| 5 | 147258254 | 147261776 | SCGB3A2 | 6 | 10695160  | 10710035  | PAK1IP1  |

|   |          |          |           |   |           |           |         |
|---|----------|----------|-----------|---|-----------|-----------|---------|
| 6 | 12012704 | 12212290 | HIVEP1    | 6 | 91223272  | 91297040  | MAP3K7  |
| 6 | 13574486 | 13615410 | SIRT5     | 6 | 100956305 | 101329263 | ASCC3   |
| 6 | 13612511 | 13633109 | NOL7      | 6 | 106632331 | 106773715 | ATG5    |
| 6 | 13621710 | 13711816 | RANBP9    | 6 | 108188940 | 108279502 | SEC63   |
| 6 | 16299323 | 16761741 | ATXN1     | 6 | 108881006 | 109005992 | FOXO3   |
| 6 | 17600498 | 17611970 | FAM8A1    | 6 | 110501604 | 110553443 | CDC40   |
| 6 | 24705069 | 24721084 | C6orf62   | 6 | 111981515 | 112194675 | FYN     |
| 6 | 26104156 | 26104585 | HIST1H4C  | 6 | 112429114 | 112575944 | LAMA4   |
| 6 | 26124350 | 26139357 | HIST1H2AC | 6 | 116892563 | 116914458 | RWDD1   |
| 6 | 31078980 | 31080352 | C6orf15   | 6 | 118228669 | 118638859 | SLC35F1 |
| 6 | 31830949 | 31846843 | SLC44A4   | 6 | 129204266 | 129837731 | LAMA2   |
| 6 | 32152490 | 32157983 | PBX2      | 6 | 131160467 | 131384482 | EPB41L2 |
| 6 | 32808474 | 32812732 | PSMB8     | 6 | 132269296 | 132272538 | CTGF    |
| 6 | 33244897 | 33246622 | B3GALT4   | 6 | 132269296 | 132272538 | CTGF    |
| 6 | 33267451 | 33282184 | TAPBP     | 6 | 134490364 | 134639216 | SGK1    |
| 6 | 33286315 | 33290813 | DAXX      | 6 | 137518601 | 137541001 | IFNGR1  |
| 6 | 34555045 | 34664645 | C6orf106  | 6 | 149068043 | 149398146 | UST     |
| 6 | 34857018 | 35085822 | ANKS1A    | 6 | 149915989 | 149970174 | KATNA1  |
| 6 | 36461646 | 36515276 | STK38     | 6 | 150045437 | 150067708 | NUP43   |
| 6 | 42931591 | 42947001 | PEX6      | 6 | 153332006 | 153452409 | RGS17   |
| 6 | 44213883 | 44221645 | HSP90AB1  | 6 | 158653248 | 158932880 | TULP4   |
| 6 | 71377454 | 71571738 | SMAP1     | 6 | 158653248 | 158932880 | TULP4   |
| 6 | 73951017 | 74019958 | KHDC1     | 6 | 158653248 | 158932880 | TULP4   |
| 6 | 74078258 | 74079535 | OOEP      | 6 | 159057486 | 159065824 | DYNLT1  |
| 6 | 74171434 | 74211199 | MTO1      | 6 | 159057486 | 159065824 | DYNLT1  |
| 6 | 74225453 | 74230775 | EEF1A1    | 6 | 160100128 | 160114373 | SOD2    |
| 6 | 83920088 | 84140958 | ME1       | 6 | 160147692 | 160177371 | WTAP    |
| 6 | 86317482 | 86353588 | SYNCRIP   | 6 | 160147692 | 160177371 | WTAP    |
| 6 | 87647004 | 87726417 | HTR1E     | 6 | 170884640 | 170893800 | PDCD2   |
| 6 | 87647004 | 87726417 | HTR1E     | 7 | 1855408   | 2272603   | MAD1L1  |

|   |          |          |          |   |           |           |         |
|---|----------|----------|----------|---|-----------|-----------|---------|
| 7 | 5566759  | 5570252  | ACTB     | 7 | 80371834  | 80551715  | SEMA3C  |
| 7 | 6414106  | 6443618  | RAC1     | 7 | 89975321  | 90020789  | GTPBP10 |
| 7 | 12726432 | 12730579 | ARL4A    | 7 | 92190052  | 92219726  | FAM133B |
| 7 | 16639381 | 16685462 | ANKMY2   | 7 | 94214516  | 94285541  | SGCE    |
| 7 | 16793331 | 16824181 | TSPAN13  | 7 | 95034154  | 95064656  | PON2    |
| 7 | 20821874 | 20826528 | SP8      | 7 | 97481409  | 97501874  | ASNS    |
| 7 | 23221426 | 23240650 | NUPL2    | 7 | 99055764  | 99063844  | ATP5J2  |
| 7 | 23221426 | 23240650 | NUPL2    | 7 | 99055764  | 99063844  | ATP5J2  |
| 7 | 26191827 | 26226777 | NFE2L3   | 7 | 99955606  | 99965474  | PILRB   |
| 7 | 27778972 | 27869406 | TAX1BP1  | 7 | 100171614 | 100183826 | LRCH4   |
| 7 | 32524925 | 32534890 | LSM5     | 7 | 100797665 | 100804577 | AP1S1   |
| 7 | 37945514 | 37956545 | SFRP4    | 7 | 101459164 | 101927270 | CUX1    |
| 7 | 38217788 | 38270292 | STARD3NL | 7 | 102952901 | 102985340 | DNAJC2  |
| 7 | 45139679 | 45151366 | TBRG4    | 7 | 104754028 | 105039634 | SRPK2   |
| 7 | 45951824 | 45960891 | IGFBP3   | 7 | 107204382 | 107218988 | DUS4L   |
| 7 | 45951824 | 45960891 | IGFBP3   | 7 | 108110846 | 108168625 | PNPLA8  |
| 7 | 55538283 | 55640220 | VOPP1    | 7 | 120988885 | 121036442 | FAM3C   |
| 7 | 55538283 | 55640220 | VOPP1    | 7 | 127950409 | 127983982 | RBM28   |
| 7 | 66093848 | 66113984 | KCTD7    | 7 | 134127087 | 134143908 | AKR1B1  |
| 7 | 66147131 | 66276471 | RABGEF1  | 7 | 135046527 | 135194895 | CNOT4   |
| 7 | 69063885 | 70257905 | AUTS2    | 7 | 138145059 | 138270353 | TRIM24  |
| 7 | 72716493 | 72722884 | NSUN5    | 7 | 138728246 | 138794486 | ZC3HAV1 |
| 7 | 73150404 | 73153210 | ABHD11   | 7 | 138728246 | 138794486 | ZC3HAV1 |
| 7 | 73703785 | 73820293 | CLIP2    | 7 | 138728246 | 138794486 | ZC3HAV1 |
| 7 | 73868100 | 74016951 | GTF2IRD1 | 7 | 139723524 | 139764106 | PARP12  |
| 7 | 74210463 | 74267892 | GTF2IRD2 | 7 | 140033532 | 140104044 | SLC37A3 |
| 7 | 75162599 | 75368310 | HIP1     | 7 | 141251058 | 141354229 | AGK     |
| 7 | 75508297 | 75518264 | RHBDD2   | 7 | 143078318 | 143088224 | ZYX     |
| 7 | 75508297 | 75518264 | RHBDD2   | 7 | 150076386 | 150095739 | ZNF775  |
| 7 | 75931855 | 75933634 | HSPB1    | 7 | 150755279 | 150773634 | SLC4A2  |

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| 7 | 150773688 | 150777990 | FASTK     | 8 | 86019303  | 86058335  | LRRCC1  |
| 7 | 151253180 | 151574336 | PRKAG2    | 8 | 90769315  | 90803312  | RIPK2   |
| 7 | 156931635 | 157062086 | UBE3C     | 8 | 92261488  | 92410398  | SLC26A7 |
| 7 | 156931635 | 157062086 | UBE3C     | 8 | 92967175  | 93115474  | RUNX1T1 |
| 7 | 157129672 | 157210153 | DNAJB6    | 8 | 97274147  | 97346794  | PTDSS1  |
| 8 | 11700013  | 11725666  | CTSB      | 8 | 98787789  | 98864850  | LAPTM4B |
| 8 | 12039593  | 12051644  | FAM86B1   | 8 | 98881264  | 99048968  | MATN2   |
| 8 | 13424332  | 13425817  | C8orf48   | 8 | 100025279 | 100890467 | VPS13B  |
| 8 | 21964363  | 21966952  | NUDT18    | 8 | 100025279 | 100890467 | VPS13B  |
| 8 | 23048950  | 23082700  | TNFRSF10A | 8 | 101269265 | 101348466 | RNF19A  |
| 8 | 26239874  | 26270664  | BNIP3L    | 8 | 117858153 | 117887125 | RAD21   |
| 8 | 27491080  | 27534306  | SCARA3    | 8 | 117858153 | 117887125 | RAD21   |
| 8 | 27950564  | 28048690  | ELP3      | 8 | 118811582 | 119124078 | EXT1    |
| 8 | 28351702  | 28431805  | FZD3      | 8 | 120428532 | 120436698 | NOV     |
| 8 | 28747891  | 28922476  | HMBOX1    | 8 | 124332070 | 124408725 | ATAD2   |
| 8 | 28747891  | 28922476  | HMBOX1    | 8 | 130851819 | 131028917 | FAM49B  |
| 8 | 29190559  | 29208287  | DUSP4     | 8 | 132916336 | 133025909 | EFR3A   |
| 8 | 30890758  | 31031297  | WRN       | 8 | 145699095 | 145701738 | FOXH1   |
| 8 | 33405252  | 33424666  | RNF122    | 8 | 146277803 | 146281436 | C8orf33 |
| 8 | 37716445  | 37757035  | RAB11FIP1 | 9 | 2015322   | 2193644   | SMARCA2 |
| 8 | 37962463  | 37997618  | ASH2L     | 9 | 3824108   | 4300056   | GLIS3   |
| 8 | 38088841  | 38120371  | DDHD2     | 9 | 6010999   | 6015660   | RANBP6  |
| 8 | 38585684  | 38710566  | TACC1     | 9 | 6413131   | 6507074   | UHRF2   |
| 8 | 42995572  | 43057990  | HGSNAT    | 9 | 19115739  | 19127624  | PLIN2   |
| 8 | 61429449  | 61536223  | RAB2A     | 9 | 19376233  | 19380292  | RPS6    |
| 8 | 67955294  | 67974582  | COPS5     | 9 | 21967731  | 21994510  | CDKN2A  |
| 8 | 70584090  | 70747319  | SLCO5A1   | 9 | 26903348  | 26947488  | PLAA    |
| 8 | 74206817  | 74237540  | RDH10     | 9 | 26903348  | 26947488  | PLAA    |
| 8 | 74888357  | 74895038  | TMEM70    | 9 | 27109127  | 27230192  | TEK     |
| 8 | 82569131  | 82599049  | IMPA1     | 9 | 27546523  | 27573884  | C9orf72 |

|   |           |           |           |    |           |           |          |
|---|-----------|-----------|-----------|----|-----------|-----------|----------|
| 9 | 32553504  | 32573202  | NDUFB6    | 9  | 134165049 | 134184669 | PPAPDC3  |
| 9 | 37485925  | 37503714  | POLR1E    | 9  | 134165049 | 134184669 | PPAPDC3  |
| 9 | 38392641  | 38398682  | ALDH1B1   | 9  | 134452137 | 134615384 | RAPGEF1  |
| 9 | 71714855  | 71870144  | TJP2      | 9  | 134735477 | 134955294 | MED27    |
| 9 | 71714855  | 71870144  | TJP2      | 9  | 134735477 | 134955294 | MED27    |
| 9 | 73143959  | 74061802  | TRPM3     | 9  | 136228305 | 136244840 | SURF4    |
| 9 | 86274858  | 86323188  | UBQLN1    | 9  | 140083009 | 140084842 | SSNA1    |
| 9 | 89559257  | 89562124  | GAS1      | 9  | 140317827 | 140328878 | NOXA1    |
| 9 | 96208756  | 96215894  | FAM120AOS | 9  | 140446289 | 140447027 | MRPL41   |
| 9 | 99075699  | 99146012  | SLC35D2   | 10 | 1034329   | 1063728   | GTPBP4   |
| 9 | 100818939 | 100845385 | NANS      | 10 | 1095403   | 1178257   | WDR37    |
| 9 | 103064337 | 103115876 | TEX10     | 10 | 5090938   | 5149898   | AKR1C3   |
| 9 | 112137954 | 112260613 | PTPN3     | 10 | 5903573   | 5931880   | ANKRD16  |
| 9 | 112137954 | 112260613 | PTPN3     | 10 | 7830073   | 7849784   | ATP5C1   |
| 9 | 114122953 | 114247045 | KIAA0368  | 10 | 13319776  | 13342153  | PHYH     |
| 9 | 114311982 | 114362155 | PTGR1     | 10 | 16632595  | 16859529  | RSU1     |
| 9 | 116037894 | 116056099 | PRPF4     | 10 | 23728178  | 23731330  | OTUD1    |
| 9 | 117781834 | 117880556 | TNC       | 10 | 27399020  | 27443369  | YME1L1   |
| 9 | 123151127 | 123342468 | CDK5RAP2  | 10 | 28966404  | 28971888  | BAMBI    |
| 9 | 123151127 | 123342468 | CDK5RAP2  | 10 | 33189226  | 33247313  | ITGB1    |
| 9 | 123617909 | 123657188 | PHF19     | 10 | 33466399  | 33623853  | NRP1     |
| 9 | 125132789 | 125158002 | PTGS1     | 10 | 35927157  | 35930382  | FZD8     |
| 9 | 125329807 | 125330776 | OR1L8     | 10 | 38383244  | 38412300  | ZNF37A   |
| 9 | 130209933 | 130213731 | RPL12     | 10 | 43084512  | 43134036  | ZNF33B   |
| 9 | 130628739 | 130640042 | AK1       | 10 | 44101835  | 44113372  | ZNF485   |
| 9 | 130830459 | 130871557 | SLC25A25  | 10 | 45471689  | 45474350  | C10orf10 |
| 9 | 130922519 | 130926227 | C9orf16   | 10 | 51592060  | 51623406  | TIMM23   |
| 9 | 131071376 | 131084717 | TRUB2     | 10 | 61410502  | 61469669  | SLC16A9  |
| 9 | 131937811 | 131940560 | IER5L     | 10 | 69556407  | 69597957  | DNAJC12  |
| 9 | 133320074 | 133376681 | ASS1      | 10 | 70100844  | 70167071  | RUFY2    |

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|----|-----------|-----------|-----------|----|-----------|-----------|----------|
| 10 | 71029720  | 71161658  | HK1       | 10 | 124739536 | 124749926 | PSTK     |
| 10 | 71962566  | 71993687  | PPA1      | 10 | 126085852 | 126107565 | OAT      |
| 10 | 75757816  | 75879938  | VCL       | 10 | 129705305 | 129884200 | PTPRE    |
| 10 | 79793498  | 79816591  | RPS24     | 10 | 133747937 | 133770074 | PPP2R2D  |
| 10 | 80828731  | 81076305  | ZMIZ1     | 11 | 494492    | 507303    | RNH1     |
| 10 | 88809939  | 88854796  | GLUD1     | 11 | 644205    | 695760    | DEAF1    |
| 10 | 90973306  | 91011680  | LIPA      | 11 | 790455    | 798289    | SLC25A22 |
| 10 | 91152283  | 91166264  | IFIT1     | 11 | 839701    | 842549    | POLR2L   |
| 10 | 93169017  | 93274606  | HECTD2    | 11 | 1968482   | 2007315   | MRPL23   |
| 10 | 93666325  | 93669278  | FGFBP3    | 11 | 2421703   | 2425128   | TSSC4    |
| 10 | 95066166  | 95242210  | MYOF      | 11 | 3876913   | 4114460   | STIM1    |
| 10 | 97889452  | 97923537  | ZNF518A   | 11 | 6642536   | 6685340   | DCHS1    |
| 10 | 98277847  | 98346829  | TM9SF3    | 11 | 8008847   | 8017738   | EIF3F    |
| 10 | 102295621 | 102313701 | HIF1AN    | 11 | 27062232  | 27149374  | BBOX1    |
| 10 | 102737559 | 102747292 | MRPL43    | 11 | 27515945  | 27528346  | LIN7C    |
| 10 | 103544180 | 103578950 | MGEA5     | 11 | 27515945  | 27528346  | LIN7C    |
| 10 | 104162354 | 104179711 | PSD       | 11 | 27676420  | 27743625  | BDNF     |
| 10 | 105036899 | 105050128 | INA       | 11 | 32914772  | 33001836  | QSER1    |
| 10 | 105206523 | 105212182 | CALHM2    | 11 | 33106110  | 33183057  | CSTF3    |
| 10 | 105353764 | 105615215 | SH3PXD2A  | 11 | 34073210  | 34124177  | CAPRIN1  |
| 10 | 105726923 | 105789011 | SLK       | 11 | 35160397  | 35253969  | CD44     |
| 10 | 111765607 | 111895343 | ADD3      | 11 | 35639715  | 35642441  | FJX1     |
| 10 | 112631533 | 112659784 | PDCD4     | 11 | 43702088  | 43878189  | HSD17B12 |
| 10 | 113907951 | 113975173 | GPAM      | 11 | 46765064  | 46867879  | CKAP5    |
| 10 | 115938995 | 115992445 | TDRD1     | 11 | 47586868  | 47595033  | PTPMT1   |
| 10 | 116581483 | 116659606 | FAM160B1  | 11 | 61066899  | 61100711  | DDB1     |
| 10 | 119764407 | 119806317 | RAB11FIP2 | 11 | 61066899  | 61100711  | DDB1     |
| 10 | 121332957 | 121356561 | TIAL1     | 11 | 62380193  | 62382612  | ROM1     |
| 10 | 124690399 | 124713939 | C10orf88  | 11 | 62475046  | 62476698  | GNG3     |
| 10 | 124739536 | 124749926 | PSTK      | 11 | 62480077  | 62494877  | HNRNPUL2 |

|    |          |          |          |    |           |           |          |
|----|----------|----------|----------|----|-----------|-----------|----------|
| 11 | 62559577 | 62572984 | NXF1     | 11 | 77589746  | 77705791  | INTS4    |
| 11 | 62574312 | 62599583 | STX5     | 11 | 85405244  | 85522217  | SYTL2    |
| 11 | 63742059 | 63744035 | COX8A    | 11 | 88026740  | 88070961  | CTSC     |
| 11 | 63753305 | 63765912 | OTUB1    | 11 | 89933577  | 89956552  | CHORDC1  |
| 11 | 63997574 | 64001773 | DNAJC4   | 11 | 93463348  | 93474723  | TAF1D    |
| 11 | 64126605 | 64139707 | RPS6KA4  | 11 | 94898657  | 94965725  | SESN3    |
| 11 | 64532056 | 64546535 | SF1      | 11 | 95566024  | 95657391  | MTMR2    |
| 11 | 64879306 | 64883727 | TM7SF2   | 11 | 102188161 | 102210154 | BIRC3    |
| 11 | 65306010 | 65325878 | LTBP3    | 11 | 102188161 | 102210154 | BIRC3    |
| 11 | 65343489 | 65360141 | EHBP1L1  | 11 | 102188161 | 102210154 | BIRC3    |
| 11 | 65360306 | 65363487 | KCNK7    | 11 | 107992238 | 108018915 | ACAT1    |
| 11 | 65601285 | 65621598 | SNX32    | 11 | 108028097 | 108093385 | NPAT     |
| 11 | 65601285 | 65621598 | SNX32    | 11 | 111652899 | 111742325 | ALG9     |
| 11 | 66202530 | 66206330 | MRPL11   | 11 | 111797848 | 111893394 | DIXDC1   |
| 11 | 66247464 | 66277150 | DPP3     | 11 | 114310088 | 114321021 | REXO2    |
| 11 | 66288834 | 66313729 | ZDHHC24  | 11 | 118967193 | 118973144 | DPAGT1   |
| 11 | 66406068 | 66435876 | RBM4     | 11 | 119225905 | 119252456 | USP2     |
| 11 | 66406068 | 66435876 | RBM4     | 11 | 120107329 | 120190673 | POU2F3   |
| 11 | 67056742 | 67069975 | ANKRD13D | 11 | 120207244 | 120360665 | ARHGEF12 |
| 11 | 67159403 | 67165903 | RAD9A    | 11 | 121322892 | 121504491 | SORL1    |
| 11 | 67374303 | 67380032 | NDUFV1   | 11 | 122526378 | 122685207 | UBASH3B  |
| 11 | 67922310 | 67981270 | SUV420H1 | 11 | 122753216 | 122830450 | C11orf63 |
| 11 | 68522068 | 68611898 | CPT1A    | 11 | 125315621 | 125366226 | FEZ1     |
| 11 | 68658724 | 68671323 | MRPL21   | 11 | 125439278 | 125454595 | EI24     |
| 11 | 71639748 | 71708663 | RNF121   | 11 | 125616160 | 125619763 | PATE1    |
| 11 | 71900582 | 71907387 | FOLR1    | 11 | 125763360 | 125773165 | PUS3     |
| 11 | 74971146 | 75062895 | ARRB1    | 12 | 3186501   | 3395750   | TSPAN9   |
| 11 | 75526192 | 75855302 | UVRAG    | 12 | 4382881   | 4414542   | CCND2    |
| 11 | 75526192 | 75855302 | UVRAG    | 12 | 6643565   | 6647557   | GAPDH    |
| 11 | 76060984 | 76091900 | PRKRIR   | 12 | 6759684   | 6772331   | ING4     |

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| 12 | 6833130  | 6841061  | COPS7A  | 12 | 64798133  | 64842484  | XPOT      |
| 12 | 7245980  | 7261889  | C1RL    | 12 | 65563331  | 65642161  | LEMD3     |
| 12 | 7341739  | 7371190  | PEX5    | 12 | 66516829  | 66524553  | LLPH      |
| 12 | 7965090  | 8043812  | SLC2A14 | 12 | 69979186  | 70010615  | CCT2      |
| 12 | 8798520  | 8815453  | MFAP5   | 12 | 72079858  | 72097860  | TMEM19    |
| 12 | 12878831 | 12944420 | APOLD1  | 12 | 72079858  | 72097860  | TMEM19    |
| 12 | 12966260 | 12982935 | DDX47   | 12 | 76745557  | 76953609  | OSBPL8    |
| 12 | 22199088 | 22218628 | CMAS    | 12 | 77415006  | 77459380  | E2F7      |
| 12 | 25358160 | 25403890 | KRAS    | 12 | 98987383  | 98995798  | SLC25A3   |
| 12 | 28110997 | 28125684 | PTHLH   | 12 | 100422213 | 100536662 | UHRF1BP1L |
| 12 | 29493559 | 29534163 | ERGIC2  | 12 | 104382742 | 104457981 | GLT8D2    |
| 12 | 32832114 | 32898604 | DNM1L   | 12 | 104458216 | 104500322 | HCFC2     |
| 12 | 39687010 | 39837212 | KIF21A  | 12 | 106631639 | 106641733 | CKAP4     |
| 12 | 45609750 | 45834207 | ANO6    | 12 | 106976665 | 107156602 | RFX4      |
| 12 | 49208195 | 49222746 | CACNB3  | 12 | 110288728 | 110318313 | GLTP      |
| 12 | 49315722 | 49319350 | FKBP11  | 12 | 110436954 | 110477257 | ANKRD13A  |
| 12 | 49396035 | 49413032 | PRKAG1  | 12 | 112123837 | 112194931 | ACAD10    |
| 12 | 52562760 | 52585818 | KRT80   | 12 | 120779113 | 120807003 | MSI1      |
| 12 | 53399922 | 53436013 | EIF4B   | 12 | 120884221 | 120901576 | GATC      |
| 12 | 53845866 | 53874966 | PCBP2   | 12 | 121200293 | 121342175 | SPPL3     |
| 12 | 53873436 | 53893464 | MAP3K12 | 12 | 121458075 | 121477065 | OASL      |
| 12 | 53901620 | 54020220 | ATF7    | 12 | 122956126 | 122985563 | ZCCHC8    |
| 12 | 54058924 | 54070532 | ATP5G2  | 12 | 122989170 | 123011580 | RSRC2     |
| 12 | 56078332 | 56109841 | ITGA7   | 12 | 122989170 | 123011580 | RSRC2     |
| 12 | 56137044 | 56146685 | GDF11   | 12 | 123237351 | 123255973 | DENR      |
| 12 | 56498083 | 56507714 | PA2G4   | 12 | 123349855 | 123380732 | VPS37B    |
| 12 | 57106191 | 57119346 | NACA    | 12 | 123405478 | 123451076 | ABCB9     |
| 12 | 58213690 | 58240767 | CTDSP2  | 12 | 123640923 | 123717805 | MPHOSPH9  |
| 12 | 59265917 | 59314339 | LRIG3   | 12 | 123955889 | 124018285 | RILPL1    |
| 12 | 64798133 | 64842484 | XPOT    | 12 | 124196845 | 124246322 | ATP6V0A2  |



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| 12 | 124457679 | 124500006 | ZNF664  | 13 | 113862487 | 113919412 | CUL4A     |
| 12 | 125549905 | 125627899 | AACS    | 13 | 114110114 | 114145044 | DCUN1D2   |
| 12 | 129277719 | 129308561 | SLC15A4 | 13 | 114238983 | 114295808 | TFDP1     |
| 12 | 129277719 | 129308561 | SLC15A4 | 13 | 115047039 | 115071312 | UPF3A     |
| 12 | 130646984 | 130650305 | FZD10   | 14 | 20811753  | 20826083  | PARP2     |
| 12 | 132434445 | 132565031 | EP400   | 14 | 21558185  | 21572883  | ZNF219    |
| 12 | 133200324 | 133264070 | POLE    | 14 | 24658333  | 24666308  | TM9SF1    |
| 12 | 133613858 | 133639905 | ZNF84   | 14 | 24658333  | 24666308  | TM9SF1    |
| 13 | 20397601  | 20437796  | ZMYM5   | 14 | 24658333  | 24666308  | TM9SF1    |
| 13 | 20397601  | 20437796  | ZMYM5   | 14 | 24701613  | 24708468  | GMPR2     |
| 13 | 25820319  | 25861724  | MTMR6   | 14 | 31091440  | 31205054  | SCFD1     |
| 13 | 27131820  | 27263102  | WASF3   | 14 | 35030595  | 35099386  | SNX6      |
| 13 | 31032857  | 31191962  | HMGB1   | 14 | 35179568  | 35184049  | CFL2      |
| 13 | 32974840  | 33002510  | N4BP2L1 | 14 | 35179568  | 35184049  | CFL2      |
| 13 | 35516404  | 36246894  | NBEA    | 14 | 35514093  | 35552609  | FAM177A1  |
| 13 | 39917009  | 40177376  | LHFP    | 14 | 36295504  | 36341189  | BRMS1L    |
| 13 | 41506035  | 41635564  | ELF1    | 14 | 39616995  | 39639654  | TRAPPC6B  |
| 13 | 41765691  | 41768722  | KBTBD7  | 14 | 45431396  | 45543654  | FAM179B   |
| 13 | 43460504  | 43566427  | EPSTI1  | 14 | 50087440  | 50090219  | MGAT2     |
| 13 | 45006259  | 45150721  | TSC22D1 | 14 | 50110250  | 50155118  | POLE2     |
| 13 | 45513364  | 45563633  | NUFIP1  | 14 | 53173874  | 53194736  | PSMC6     |
| 13 | 45513364  | 45563633  | NUFIP1  | 14 | 53196863  | 53241727  | STYX      |
| 13 | 49882766  | 50018241  | CAB39L  | 14 | 54941182  | 54955805  | GMFB      |
| 13 | 50018409  | 50069159  | SETDB2  | 14 | 55518342  | 55536932  | MAPK1IP1L |
| 13 | 52586503  | 52603804  | ALG11   | 14 | 58470788  | 58618867  | C14orf37  |
| 13 | 53226810  | 53262453  | SUGT1   | 14 | 58711503  | 58738747  | PSMA3     |
| 13 | 72012078  | 72441350  | DACH1   | 14 | 58711503  | 58738747  | PSMA3     |
| 13 | 72012078  | 72441350  | DACH1   | 14 | 60611476  | 60633054  | DHRS7     |
| 13 | 78469596  | 78549684  | EDNRB   | 14 | 63671060  | 63760250  | RHOJ      |
| 13 | 79188401  | 79233334  | RNF219  | 14 | 65007166  | 65009975  | HSPA2     |

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| 14 | 65171112  | 65213643  | PLEKHG3   | 14 | 105266913 | 105271069 | ZBTB42   |
| 14 | 65472799  | 65569433  | MAX       | 14 | 105452105 | 105466076 | C14orf79 |
| 14 | 66974105  | 67648545  | GPHN      | 14 | 105452105 | 105466076 | C14orf79 |
| 14 | 67827014  | 67853253  | EIF2S1    | 14 | 105714859 | 105717450 | BTBD6    |
| 14 | 68143497  | 68162530  | RDH11     | 14 | 105952872 | 105955148 | CRIP1    |
| 14 | 73957624  | 73960125  | C14orf169 | 15 | 22833375  | 22873911  | TUBGCP5  |
| 14 | 74111558  | 74170451  | DNAL1     | 15 | 22892647  | 23003623  | CYFIP1   |
| 14 | 76044920  | 76114532  | FLVCR2    | 15 | 23888676  | 23893013  | MAGEL2   |
| 14 | 77248056  | 77292626  | ANGEL1    | 15 | 25068774  | 25223750  | SNRPN    |
| 14 | 91006912  | 91282843  | TTC7B     | 15 | 35270522  | 35280517  | ZNF770   |
| 14 | 92588278  | 92630563  | CPSF2     | 15 | 40226311  | 40327817  | EIF2AK4  |
| 14 | 93170132  | 93215067  | LG MN     | 15 | 40226311  | 40327817  | EIF2AK4  |
| 14 | 93403239  | 93582283  | ITPK1     | 15 | 49030115  | 49104112  | CEP152   |
| 14 | 93669217  | 93673479  | C14orf142 | 15 | 51739901  | 51915050  | DMXL2    |
| 14 | 93703876  | 93799405  | BTBD7     | 15 | 52230202  | 52264015  | LEO1     |
| 14 | 94594098  | 94595977  | IFI27L2   | 15 | 60780463  | 61521522  | RORA     |
| 14 | 94594098  | 94595977  | IFI27L2   | 15 | 63413979  | 63434280  | LACTB    |
| 14 | 96152734  | 96159000  | TCL1B     | 15 | 63796690  | 63886859  | USP3     |
| 14 | 100150735 | 100193658 | CYP46A1   | 15 | 64364741  | 64386227  | FAM96A   |
| 14 | 100204036 | 100408417 | EML1      | 15 | 64457696  | 64665988  | CSNK1G1  |
| 14 | 100204036 | 100408417 | EML1      | 15 | 65255343  | 65282271  | SPG21    |
| 14 | 101003464 | 101036151 | BEGAIN    | 15 | 66994654  | 67074358  | SMAD6    |
| 14 | 101193182 | 101201487 | DLK1      | 15 | 72533502  | 72564905  | PARP6    |
| 14 | 102430845 | 102517155 | DYNC1H1   | 15 | 74833498  | 74890492  | ARID3B   |
| 14 | 102547055 | 102606106 | HSP90AA1  | 15 | 74898307  | 74922562  | CLK3     |
| 14 | 102606169 | 102690030 | WDR20     | 15 | 75661700  | 75748201  | SIN3A    |
| 14 | 102973159 | 102976148 | ANKRD9    | 15 | 75759442  | 75871645  | PTPN9    |
| 14 | 103995489 | 104003430 | TRMT61A   | 15 | 78463167  | 78527069  | ACSBG1   |
| 14 | 103995489 | 104003430 | TRMT61A   | 15 | 85212748  | 85259711  | SEC11A   |
| 14 | 105190514 | 105213682 | ADSSL1    | 15 | 89178884  | 89198901  | ISG20    |

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| 15 | 89441894 | 89456705 | MFGES   | 16 | 29452581 | 29466305 | BOLA2     |
| 15 | 90293078 | 90294560 | MESPI   | 16 | 29973331 | 29984393 | TMEM219   |
| 15 | 90773457 | 90809011 | CIB1    | 16 | 30016815 | 30023444 | DOC2A     |
| 15 | 91260559 | 91358706 | BLM     | 16 | 30535302 | 30538841 | ZNF768    |
| 15 | 91473390 | 91497343 | UNC45A  | 16 | 30709005 | 30709830 | LOC730183 |
| 15 | 92396918 | 92715685 | SLCO3A1 | 16 | 30960385 | 30966279 | ORA13     |
| 15 | 92396918 | 92715685 | SLCO3A1 | 16 | 46918288 | 46965221 | GPT2      |
| 15 | 93586616 | 93632463 | RGMA    | 16 | 48278191 | 48387908 | LONP2     |
| 16 | 126998   | 135870   | MPG     | 16 | 56485404 | 56511427 | OGFOD1    |
| 16 | 222826   | 223729   | HBA2    | 16 | 56504281 | 56554028 | BBS2      |
| 16 | 222826   | 223729   | HBA2    | 16 | 56763997 | 56882657 | NUP93     |
| 16 | 446732   | 450774   | NME4    | 16 | 58497529 | 58547543 | NDRG4     |
| 16 | 691829   | 698494   | FAM195A | 16 | 58497529 | 58547543 | NDRG4     |
| 16 | 770561   | 772675   | FAM173A | 16 | 66541886 | 66584335 | TK2       |
| 16 | 1877205  | 1890228  | FAHD1   | 16 | 67423690 | 67427469 | TPPP3     |
| 16 | 1877205  | 1890228  | FAHD1   | 16 | 67596290 | 67673108 | CTCF      |
| 16 | 2028898  | 2031724  | NOXO1   | 16 | 67708416 | 67753293 | GFOD2     |
| 16 | 2089796  | 2097951  | NTHL1   | 16 | 67906906 | 67918437 | EDC4      |
| 16 | 2205743  | 2228150  | TRAF7   | 16 | 67977357 | 68002617 | SLC12A4   |
| 16 | 2732475  | 2759051  | KCTD5   | 16 | 69373395 | 69377034 | NIP7      |
| 16 | 3333360  | 3351421  | ZNF263  | 16 | 70488478 | 70514197 | FUK       |
| 16 | 3355386  | 3372955  | ZNF75A  | 16 | 70721322 | 70835094 | VAC14     |
| 16 | 3451170  | 3459384  | ZNF174  | 16 | 72127595 | 72146831 | DHX38     |
| 16 | 4404523  | 4466982  | CORO7   | 16 | 75622698 | 75657241 | ADAT1     |
| 16 | 4404523  | 4466982  | CORO7   | 16 | 78133290 | 79246587 | WVOX      |
| 16 | 8889017  | 8891525  | TMEM186 | 16 | 84087348 | 84150537 | MBTPS1    |
| 16 | 11641558 | 11681342 | LITAF   | 16 | 84087348 | 84150537 | MBTPS1    |
| 16 | 19727758 | 19869107 | IQCK    | 16 | 84155724 | 84178820 | HSDL1     |
| 16 | 22357237 | 22385958 | CDR2    | 16 | 89334009 | 89556989 | ANKRD11   |
| 16 | 25123027 | 25189571 | LCMT1   | 16 | 89574782 | 89624194 | SPG7      |

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| 16 | 89613304 | 89633257 | RPL13    | 17 | 26684667 | 26689109 | TMEM199  |
| 16 | 89613304 | 89633257 | RPL13    | 17 | 27055802 | 27069804 | NEK8     |
| 16 | 89753056 | 89762792 | CDK10    | 17 | 30469453 | 30552766 | RHOT1    |
| 16 | 89762745 | 89768151 | SPATA2L  | 17 | 34623822 | 34625750 | CCL3L1   |
| 16 | 90071259 | 90085957 | DBNDD1   | 17 | 34623822 | 34625750 | CCL3L1   |
| 17 | 1324627  | 1359581  | CRK      | 17 | 34842451 | 34855174 | ZNHIT3   |
| 17 | 1367460  | 1396021  | MYO1C    | 17 | 34842451 | 34855174 | ZNHIT3   |
| 17 | 2207224  | 2228573  | SRR      | 17 | 34900717 | 34946298 | GGNBP2   |
| 17 | 2240786  | 2284373  | SGSM2    | 17 | 36452969 | 36479121 | MRPL45   |
| 17 | 4046421  | 4061015  | CYB5D2   | 17 | 36584700 | 36668648 | ARHGAP23 |
| 17 | 4688560  | 4689749  | VMO1     | 17 | 37006301 | 37010073 | RPL23    |
| 17 | 4840405  | 4843482  | SLC25A11 | 17 | 37356516 | 37361000 | RPL19    |
| 17 | 4848925  | 4852401  | PFN1     | 17 | 37408877 | 37558550 | FBXL20   |
| 17 | 4853384  | 4860446  | ENO3     | 17 | 37827355 | 37844330 | PGAP3    |
| 17 | 6481625  | 6545086  | KIAA0753 | 17 | 38060828 | 38074923 | GSDMB    |
| 17 | 7323632  | 7324976  | SPEM1    | 17 | 40128419 | 40169735 | DNAJC7   |
| 17 | 7465289  | 7475307  | SENP3    | 17 | 40276974 | 40307082 | RAB5C    |
| 17 | 7476004  | 7482344  | EIF4A1   | 17 | 40731506 | 40761465 | FAM134C  |
| 17 | 7482785  | 7485449  | CD68     | 17 | 40761338 | 40767276 | TUBG1    |
| 17 | 7494528  | 7518235  | FXR2     | 17 | 40925434 | 40931638 | VPS25    |
| 17 | 7554234  | 7561109  | ATP1B2   | 17 | 41166602 | 41174479 | VAT1     |
| 17 | 7571700  | 7590888  | TP53     | 17 | 41177238 | 41184078 | RND2     |
| 17 | 8243138  | 8249384  | ODF4     | 17 | 42422471 | 42430494 | GRN      |
| 17 | 15848211 | 15879230 | ADORA2B  | 17 | 42927635 | 42977013 | EFTUD2   |
| 17 | 16284347 | 16286079 | UBB      | 17 | 42977060 | 42983561 | CCDC103  |
| 17 | 17397731 | 17399729 | RASD1    | 17 | 43100686 | 43138493 | DKAKD    |
| 17 | 18853969 | 18924024 | SLC5A10  | 17 | 43299172 | 43324705 | FMNL1    |
| 17 | 19314471 | 19320609 | RNF112   | 17 | 44668015 | 44834850 | NSF      |
| 17 | 19552044 | 19580928 | ALDH3A2  | 17 | 45331188 | 45390097 | ITGB3    |
| 17 | 20352688 | 20370868 | LGALS9B  | 17 | 47074754 | 47133527 | IGF2BP1  |

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| 17 | 54869254 | 54911276 | C17orf67 | 18 | 158463   | 213759   | USP14    |
| 17 | 54869254 | 54911276 | C17orf67 | 18 | 3411905  | 3458429  | TGIF1    |
| 17 | 54965250 | 54991429 | TRIM25   | 18 | 9708208  | 9862573  | RAB31    |
| 17 | 55333911 | 55762070 | MSI2     | 18 | 10454605 | 10488718 | APCDD1   |
| 17 | 56422516 | 56429619 | SUPT4H1  | 18 | 12308198 | 12326588 | TUBB6    |
| 17 | 56597591 | 56618199 | SEPT4    | 18 | 12785457 | 12884357 | PTPN2    |
| 17 | 57187288 | 57232820 | SKA2     | 18 | 21086128 | 21166601 | NPC1     |
| 17 | 62494354 | 62503062 | DDX5     | 18 | 28645918 | 28682408 | DSC2     |
| 17 | 66031828 | 66042990 | KPNA2    | 18 | 29078007 | 29128834 | DSG2     |
| 17 | 71161140 | 71168114 | SSTR2    | 18 | 32820974 | 32838417 | ZNF397   |
| 17 | 71244568 | 71258039 | CPSF4L   | 18 | 32820974 | 32838417 | ZNF397   |
| 17 | 72199775 | 72206039 | RPL38    | 18 | 33688474 | 33709377 | SLC39A6  |
| 17 | 72427460 | 72447817 | GPRC5C   | 18 | 43664090 | 43684219 | ATP5A1   |
| 17 | 72427460 | 72447817 | GPRC5C   | 18 | 44056915 | 44237016 | LOXHD1   |
| 17 | 73163805 | 73179118 | SUMO2    | 18 | 46567826 | 46987192 | DYM      |
| 17 | 73496321 | 73511684 | CASKIN2  | 18 | 47014831 | 47018955 | RPL17    |
| 17 | 73663379 | 73704159 | SAP30BP  | 18 | 51677951 | 51751178 | MBD2     |
| 17 | 74466955 | 74497529 | RHBDF2   | 18 | 51884264 | 51908424 | C18orf54 |
| 17 | 74708894 | 74722901 | JMJD6    | 18 | 54270033 | 54305940 | TXNL1    |
| 17 | 75277472 | 75496698 | SEPT9    | 18 | 55267868 | 55289197 | NARS     |
| 17 | 76352838 | 76356180 | SOCS3    | 18 | 59711437 | 59854309 | PIGN     |
| 17 | 76670110 | 76778396 | CYTH1    | 18 | 60790559 | 60987031 | BCL2     |
| 17 | 76849039 | 76921492 | TIMP2    | 18 | 65173799 | 65183987 | DSEL     |
| 17 | 77018996 | 77045890 | C1QTNF1  | 18 | 65173799 | 65183987 | DSEL     |
| 17 | 78075319 | 78093700 | GAA      | 18 | 71920507 | 71959271 | CYB5A    |
| 17 | 78234623 | 78372606 | RNF213   | 18 | 72265086 | 72777648 | ZNF407   |
| 17 | 78440613 | 78450424 | NPTX1    | 18 | 77866895 | 77898249 | ADNP2    |
| 17 | 79213019 | 79215118 | C17orf89 | 19 | 305555   | 344811   | MIER2    |
| 17 | 79218779 | 79269253 | SLC38A10 | 19 | 416563   | 461016   | SHC2     |
| 17 | 79648204 | 79650974 | ARL16    | 19 | 1026254  | 1039084  | CNN2     |

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|----|----------|----------|----------|----|----------|----------|---------|
| 19 | 1065902  | 1086647  | HMHA1    | 19 | 17830283 | 17845344 | MAP1S   |
| 19 | 1383506  | 1395608  | NDUFS7   | 19 | 18723662 | 18731869 | TMEM59L |
| 19 | 1481407  | 1490906  | PCSK4    | 19 | 18942724 | 18979059 | UPF1    |
| 19 | 1815225  | 1848540  | REXO1    | 19 | 19734444 | 19739059 | LPAR2   |
| 19 | 2328609  | 2355120  | SPPL2B   | 19 | 20278000 | 20311319 | ZNF486  |
| 19 | 3359541  | 3469235  | NFIC     | 19 | 20802725 | 20844422 | ZNF626  |
| 19 | 5830617  | 5839784  | FUT6     | 19 | 30302785 | 30315244 | CCNE1   |
| 19 | 6661244  | 6670619  | TNFSF14  | 19 | 33087887 | 33166122 | ANKRD27 |
| 19 | 7599013  | 7626673  | PNPLA6   | 19 | 33877835 | 34012819 | PEPD    |
| 19 | 7953370  | 7966928  | LRRC8E   | 19 | 35759876 | 35770744 | USF2    |
| 19 | 8023437  | 8070549  | ELAVL1   | 19 | 35759876 | 35770744 | USF2    |
| 19 | 9361700  | 9362759  | OR7E24   | 19 | 36233408 | 36236429 | U2AF1L4 |
| 19 | 9473676  | 9493313  | ZNF177   | 19 | 36236458 | 36238076 | PSENE1  |
| 19 | 9920923  | 9930121  | FBXL12   | 19 | 36486070 | 36487240 | SDHAF1  |
| 19 | 9964374  | 10047090 | OLFM2    | 19 | 36705484 | 36729696 | ZNF146  |
| 19 | 10070217 | 10121167 | COL5A3   | 19 | 36936001 | 36980824 | ZNF566  |
| 19 | 10828709 | 10944189 | DNM2     | 19 | 37638320 | 37663663 | ZNF585A |
| 19 | 10828709 | 10944189 | DNM2     | 19 | 38893755 | 38899748 | FAM98C  |
| 19 | 10982233 | 11033473 | CARM1    | 19 | 39327008 | 39342999 | HNRNPL  |
| 19 | 12799710 | 12807669 | FBXW9    | 19 | 39421328 | 39423680 | MRPS12  |
| 19 | 13056608 | 13064477 | RAD23A   | 19 | 40021610 | 40023514 | EID2B   |
| 19 | 13207982 | 13213994 | LYL1     | 19 | 40021610 | 40023514 | EID2B   |
| 19 | 13885237 | 13889607 | C19orf53 | 19 | 40029426 | 40030858 | EID2    |
| 19 | 13906238 | 13943088 | ZSWIM4   | 19 | 41099052 | 41135745 | LTBP4   |
| 19 | 15270424 | 15311812 | NOTCH3   | 19 | 41256705 | 41271317 | SNRPA   |
| 19 | 16435631 | 16438365 | KLF2     | 19 | 41725084 | 41767692 | AXL     |
| 19 | 16940189 | 16991186 | SIN3B    | 19 | 41931244 | 41934655 | B3GNT8  |
| 19 | 17186571 | 17324124 | MYO9B    | 19 | 42460813 | 42463550 | RABAC1  |
| 19 | 17502218 | 17516478 | BST2     | 19 | 42751697 | 42759329 | ERF     |
| 19 | 17622258 | 17632117 | PGLS     | 19 | 42788714 | 42799969 | CIC     |

|    |          |          |          |    |          |          |         |
|----|----------|----------|----------|----|----------|----------|---------|
| 19 | 42801165 | 42806972 | PAFAH1B3 | 20 | 5095579  | 5107288  | PCNA    |
| 19 | 42891151 | 42894464 | CNFN     | 20 | 5931278  | 5975872  | MCM8    |
| 19 | 44150227 | 44174518 | PLAUR    | 20 | 25176307 | 25207385 | ENTPD6  |
| 19 | 44416756 | 44439431 | ZNF45    | 20 | 25176307 | 25207385 | ENTPD6  |
| 19 | 44529474 | 44537283 | ZNF222   | 20 | 25275359 | 25371638 | ABHD12  |
| 19 | 46213867 | 46234171 | FBXO46   | 20 | 25275359 | 25371638 | ABHD12  |
| 19 | 46969728 | 46974840 | PNMAL1   | 20 | 30865423 | 30922834 | KIF3B   |
| 19 | 47177553 | 47220404 | PRKD2    | 20 | 30865423 | 30922834 | KIF3B   |
| 19 | 49118564 | 49122695 | RPL18    | 20 | 31407679 | 31438231 | MAPRE1  |
| 19 | 49467639 | 49470156 | FTL      | 20 | 32077908 | 32237857 | CBFA2T2 |
| 19 | 49467639 | 49470156 | FTL      | 20 | 32868051 | 32899628 | AHCY    |
| 19 | 49471362 | 49496630 | GYS1     | 20 | 33302558 | 33413453 | NCOA6   |
| 19 | 50194343 | 50217008 | CPT1C    | 20 | 33462746 | 33515789 | ACSS2   |
| 19 | 50410062 | 50433008 | NUP62    | 20 | 33516216 | 33543814 | GSS     |
| 19 | 51009234 | 51014632 | JOSD2    | 20 | 33866689 | 33872639 | EIF6    |
| 19 | 51870332 | 51872518 | CLDND2   | 20 | 34236827 | 34252898 | RBM12   |
| 19 | 52020931 | 52035130 | SIGLEC6  | 20 | 34256590 | 34287307 | NFS1    |
| 19 | 52359036 | 52391249 | ZNF577   | 20 | 34287212 | 34288922 | ROMO1   |
| 19 | 52392468 | 52408325 | ZNF649   | 20 | 34995424 | 35157060 | DLGAP4  |
| 19 | 54369591 | 54379709 | MYADM    | 20 | 35169867 | 35178246 | MYL9    |
| 19 | 54494383 | 54515940 | CACNG6   | 20 | 43124844 | 43150746 | SERINC3 |
| 19 | 55385529 | 55401859 | FCAR     | 20 | 43248140 | 43280396 | ADA     |
| 19 | 57862625 | 57871286 | ZNF304   | 20 | 43380425 | 43438999 | RIMS4   |
| 19 | 58944161 | 58951609 | ZNF132   | 20 | 43514220 | 43537193 | YWHAB   |
| 20 | 388676   | 411630   | RBCK1    | 20 | 43720930 | 43729773 | KCNS1   |
| 20 | 1349601  | 1373836  | FKBP1A   | 20 | 44420556 | 44440086 | DNTTIP1 |
| 20 | 2082508  | 2129221  | STK35    | 20 | 44978147 | 44993117 | SLC35C2 |
| 20 | 2462443  | 2489798  | ZNF343   | 20 | 46286130 | 46415380 | SULF2   |
| 20 | 3208043  | 3222129  | SLC4A11  | 20 | 46286130 | 46415380 | SULF2   |
| 20 | 5095579  | 5107288  | PCNA     | 20 | 48552894 | 48570442 | RNF114  |

|    |          |          |         |    |          |          |          |
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| 20 | 49551384 | 49575101 | DPM1    | 22 | 21271694 | 21308057 | CRKL     |
| 20 | 52824482 | 52836512 | PFDN4   | 22 | 21369422 | 21382322 | P2RX6    |
| 20 | 56884751 | 56942583 | RAB22A  | 22 | 22113926 | 22221990 | MAPK1    |
| 20 | 58511867 | 58515372 | PPP1R3D | 22 | 24108001 | 24110161 | CHCHD10  |
| 20 | 60877092 | 60884226 | ADRM1   | 22 | 24313534 | 24322039 | DDT      |
| 20 | 61273775 | 61317157 | SLCO4A1 | 22 | 25348656 | 25593435 | KIAA1671 |
| 20 | 61472447 | 61493135 | TCFL5   | 22 | 26921694 | 26986109 | TPST2    |
| 20 | 61826761 | 61847558 | YTHDF1  | 22 | 26921694 | 26986109 | TPST2    |
| 20 | 61924518 | 61962305 | COL20A1 | 22 | 29168642 | 29185303 | CCDC117  |
| 20 | 62151406 | 62153544 | PPDPF   | 22 | 29702965 | 29708798 | GAS2L1   |
| 20 | 62588037 | 62601243 | ZNF512B | 22 | 31058019 | 31063894 | DUSP18   |
| 20 | 62612397 | 62664473 | PRPF6   | 22 | 31500743 | 31503571 | SELM     |
| 20 | 62711431 | 62732016 | OPRL1   | 22 | 35653425 | 35691820 | HMGXB4   |
| 21 | 18965948 | 18985288 | BTG3    | 22 | 36677303 | 36784127 | MYH9     |
| 21 | 35790890 | 35884593 | KCNE1   | 22 | 37865081 | 37882519 | MFNG     |
| 21 | 37529060 | 37666592 | DOPEY2  | 22 | 38302135 | 38338485 | MICALL1  |
| 21 | 38123169 | 38362565 | HLCS    | 22 | 38686677 | 38714109 | CSNK1E   |
| 21 | 38123169 | 38362565 | HLCS    | 22 | 38864047 | 38879472 | KDEL3    |
| 21 | 38445534 | 38575428 | TTC3    | 22 | 38864047 | 38879472 | KDEL3    |
| 21 | 40556082 | 40685765 | BRWD1   | 22 | 38879423 | 38903642 | DDX17    |
| 21 | 44394623 | 44453708 | PKNOX1  | 22 | 39101713 | 39129612 | GTPBP1   |
| 21 | 45193526 | 45196276 | CSTB    | 22 | 39257448 | 39268278 | CBX6     |
| 21 | 45193526 | 45196276 | CSTB    | 22 | 39436589 | 39451997 | APOBEC3F |
| 21 | 46934609 | 46983065 | SLC19A1 | 22 | 39436589 | 39451997 | APOBEC3F |
| 21 | 46934609 | 46983065 | SLC19A1 | 22 | 40806272 | 41032710 | MKL1     |
| 21 | 47518013 | 47552783 | COL6A2  | 22 | 42017230 | 42060072 | XRCC6    |
| 22 | 18900186 | 18924086 | PRODH   | 22 | 42069917 | 42085316 | NHP2L1   |
| 22 | 20103441 | 20114900 | RANBP1  | 22 | 42229063 | 42303332 | SREBF2   |
| 22 | 20119344 | 20135550 | ZDHHC8  | 22 | 42979707 | 43010988 | POLDIP3  |
| 22 | 21271694 | 21308057 | CRKL    | 22 | 43013826 | 43045425 | CYB5R3   |



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| 22 | 43013826 | 43045425 | CYB5R3  |
| 22 | 43192510 | 43253428 | ARFGAP3 |
| 22 | 46316226 | 46373028 | WNT7B   |
| 22 | 46731278 | 46753257 | TRMU    |
| 22 | 51017367 | 51021448 | CHKB    |
| 22 | 51061162 | 51066621 | ARSA    |
| 22 | 51113050 | 51171660 | SHANK3  |