Bioinformatics analysis of lncRNAs differently expressed in patients with schizophrenia

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Abstract
This study aimed to perform bioinformatics analysis of differentially expressed NONHSAT089447, NONHSAT021545 and NONHSAT041499 and their co-expressed mRNAs in blood samples of patients with schizophrenia, to provide the theoretical basis for further research. We screened the peripheral blood mononuclear cells in 5 patients and 5 controls, 10 differentially expressed IncRNAs were selected and validated in 106 patients and 48 controls by qPCR. The co-expressed mRNAs of IncRNAs were identified by calculating Pearson correlation, and the result were analyzed by gene ontology and KEGG pathway analysis using DAVID. Then an IncRNA-transcription factor-gene network was performed. The co-expressed mRNAs of IncRNAs were participate in diverse GO biological processes, among which some terms have direct relationship with the central nervous system; The pathway analysis showed that a significant enrichment in ribosome, lysosome, amyotrophic lateral sclerosis, glycolysis/Gluconeogenesis, GnrH signaling pathway, hematopoietic cell lineage, leukocyte transendothelial migration, mTOR signaling pathway, insulin signaling pathway and apoptosis; LncRNA-transcription factor-gene network showed that TAF1, EBF1 and USF1 were important transcription factors and that 15 genes (RPL13A, RPL12, RPL10A, RPS2, CASC4, HIST1H4E, PTMA, RPL17, RPL26, RPL3, RPS18, SH2B3, SLC15A4, TPP1, TRAPPCL2) may play a key role in schizophrenia. Bioinformatics analysis indicates that NONHSAT089447, NONHSAT021545 and NONHSAT041499 and their co-expressed mRNAs are closely related to the mechanism and pathogenesis of schizophrenia.

Introduction
Schizophrenia (SZ) has been one of the most disabling mental disorders with onset usually in early adulthood, imposing great social burden and paralyzing individuals’ life. To date, the pathomechanism of SZ is unclear, although current evidence demonstrated that interactions between environmental and genetic factors contribute to SZ development [1]. It has always been the major goal of investigators to understand the underlying pathophysiology of SZ and to determine effective treatment approaches for SZ patients [2]. The major obstacle in achieving this goal is the absence of reliable and simple biomarkers based on SZ diagnose and antipsychotic responses [3,4].

In recent years, noncoding RNAs (ncRNAs) has become the focus of study around the globe, among which microRNA has been fully tapped in a great variety of diseases. Unfortunately, inconsistent results have made it so difficult to yield significant conclusions. Therefore, more valid biomarkers for psychiatric diseases warrant notice. IncRNAs are noncoding transcripts longer than 200 nucleotides, that are increasingly appreciated as important regulators of gene expression. Previously, IncRNAs were often considered to be transcriptional ‘noise’ [5]. However, in recent years, accumulating evidences indicates that several IncRNAs may act as modular scaffolds, combining multiple nucleic acid and protein binding domains to interact functionally with the activity of multiple effector proteins [6-8]. This suggests that IncRNAs may have critical roles in a wide range of biological processes, including the regulation of gene expression, cell proliferation and differentiation, and disease [9]. Recent researches indicate that IncRNAs may play a potential role in neurodevelopmental, neurodegenerative and psychiatric disease and brain cancer [7]. IncRNAs are often expressed in a highly cell type-dependent or tissue-specific manner and can be detected in peripheral blood in many neuropsychiatric diseases [10]. Because its characteristics of noninvasive, easy accessibility, high measurement accuracy, and cost-effective, circulating IncRNAs may potentially serve as novel biomarkers of SZ [10,11]. However, there have been hardly any studies on the IncRNAs expression profile in peripheral blood of S patients and on investigating their response to antipsychotics medications have been conducted.

Altered expressions of IncRNAs have been demonstrated to contribute to genetic and biological basis of neuropsychiatric disorders, including Alzheimer’s disease (AD) Arisi et al. [12], major depressive disorder(MDD) Liuet al. [13], Parkinson’s disease(PD) Saietal. [14], and amyotrophic lateral sclerosis (ALS) [15]. Using Logic Mining method, Arisi et al. analyzed the microarray expression dataset of antiNGF AD11 transgenic mouse model and foundSox20T and 181004B01Rik

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would serve as the best biomarkers of neurodegeneration in both early and late stages [12]. Mercer et al. found 849 ncRNAs expressed in the adult mouse brain, majorities were associated with specific neuroanatomical regions, cell types, or subcellular compartments [16]. One recent study profiled the expression of 34834 IncRNAs and 39224 mRNAs in peripheral blood sampled from MDD patients as well as demographically-matched controls. The results revealed that 2007 IncRNAs and 1667 mRNAs were differentially expressed, 17 of which were documented as depression related gene in previous studies [17]. Although the association between aberrant IncRNAs expression and SZ has been investigated, the pharmacological effects of antipsychotic treatment on IncRNAs expression are largely unknown.

We already found out that there were three IncRNAs, namely NONHSAT089447, NONHSAT021545 and NONHSAT041499, which had differentially expressed in schizophrenia patients based upon microarray analysis and PCR verification. In this study, we used bioinformatics methodology to predict the target genes of IncRNA that were aberrantly expressed in the peripheral blood in SZ patients and GO functional enrichment analysis and KEGG pathways enrichment analysis were applied in an effort to explore further into the role of certain IncRNA involved in the molecular mechanism of schizophrenia.

Materials and methods

Patients

A total of 106 SZ patients, 54 male and 52 female, who met the diagnostic criteria as defined by the Diagnostic and Statistical Manual of Mental Disorders, 4th Edition for SZ were enrolled from No.102 Hospital of the People’s Liberation Army from October 2012 to June 2014. All patients, aged from 15 to 80, were drug naïve from any antipsychotic treatment, or in the absence of antipsychotic medication within at least 3 months before enrollment. The exclusion criteria were as follow: a personal history of severe medical diseases, other psychiatric disorders, structural brain disorders, cognitive disability, unstable psychiatric features and movement disorders. Also, patients who had brain injury causing traumatic amnesia longer than 24 hours, and who received blood transfusion within 1 month or electroconvulsive therapy within 6 months, were excluded from the study.

Forty-eight healthy controls, 25 male and 23 female, without any family history of major psychiatric disorders (SZ, bipolar disorder, and major depressive disorder) within the last three generations were recruited. Similarly, all healthy controls were without any history of blood transfusion or severe traumatic event within 1 month. Patients and healthy controls were matched in gender, age and ethnicity. The study was approved by the local Institutional Review Board. Written informed consent was obtained from all participants.

Blood collection and RNA extraction

Whole blood (5 ml) was collected in EDTA anticoagulant tube from each subject and processed within 1 hour. PBMCs were isolated from the blood through density gradient centrifugation and stored at -80°C until use. Total RNAs were isolated from the PBMCs using Trizol (Invitrogen, Carlsbad, CA, USA) and the RNeasy kit (Qiagen, Hilden, Germany) according to the manufacturer’s protocol, quantified by NanoDrop (Thermo Scientific, Delaware, ME, USA), DNase treated (TurbodNase, Life Technologies) and reverse transcribed (Superscript III; Invitrogen). The integration of RNA was confirmed by gel electrophoresis.

IncRNA microarray expression profiling

RNA samples from 5 SZ patients (male, 23 years; male, 31 years; male, 33 years; female, 28 years; female, 42 years) and 5 controls (male, 20 years; male, 33 years; male, 34 years; female, 26 years; female, 43 years) were used for IncRNA microarray profiling. IncRNA expression was measured by Human IncRNA 3.0 array (Arraystar, Santa Clara, CA, USA). The sample labeling, microarray hybridization and washing were performed based on the manufacturer’s standard protocols. Afterwards, the labeled RNAs were hybridized onto the microarray. Having washed and stained the slides, the arrays were scanned by the Agilent Scanner G2505C (Agilent). The scanned images were analyzed using Feature Extraction software (version10.7.1.1, Agilent Technologies) and Gene spring software (version 12.5; Agilent Technologies).

Real-time quantitative reverse-transcription PCR (qRT-PCR)

According to microarray results, the top IncRNAs with the highest expression changes were chosen for further validation with qRT-PCR. Blood samples from 106 SZ patients and 48 controls were used to validate the candidate IncRNAs. Total RNAs were isolated from the PBMCs using Trizol reagent (Invitrogen®, USA) for quantitative detection of IncRNA. Complementary DNA was synthesized using the Reverse Transcription TaqMan RNA Reverse Transcription Kit (Applied Biosystems, inc., USA) according to the manufacturer’s instructions. Real-time PCR was performed using Applied Biosystems 7900HT Real-Time PCR System (Applied Biosystems, Inc., USA). Data were collected using the SDS 2.3 software (Applied Biosystems, Inc.) and DataAssist v3.0 software. After normalized to β-Actin, the expression levels of IncRNAs were calculated using the 2-ΔΔCt method.

Statistical analysis

Statistical analyses were carried out using Statistical Package for Social Sciences (SPSS) for Windows 22.0, Data Assist 3.0, and Graph pad Prism 5.01. Mann-Whitney U test was performed to test the differences of 10 IncRNAs between SZ and healthy controls subjects. IncRNAs data were presented as fold change relative to the control group (control=1). Pearson correlation test was carried out for testing the correlation of IncRNAs expression level change with symptomatology scores changes. The difference in coping style between higher IncRNA expression subgroup and lower IncRNA expression subgroup were also measured by independent sample t test. All statistical tests were two-tailed and P-values of <0.05 was considered to indicate significant differences. The correlations between the expression of NONHSAT089447, NONHSAT021545 and NONHSAT041499 and the expression of differentially expressed mRNA in microarray analysis were made, and the mRNA co-expressed with IncRNA were identified by the criteria of P <0.05 and r>0.7.

GO and KEGG pathway enrichment analysis

We used the database for annotation, visualization and integrated discovery (DAVID) (http://david.abcc.ncifcrf.gov/) to make GO and KEGG pathway enrichment analysis of the three-mRNA co-expressed with IncRNA. A significant threshold of P value was set as 0.1 by readjusted Fisher exact probability test.

Correlation between IncRNA and transcription factors

The overlap between the coding gene set co-expressed with IncRNA and the target gene set of transcription factors was calculated. The enrichment of this overlap set was measured by hypergeometric
distribution and the significant lncRNA-relevant transcription factors were identified, among which the ones that played a joint regulating role with lncRNA might be identified. We further used the Cytoscape software to construct topographical map of the interaction between lncRNAs and transcription factors and target genes.

Results

LncRNA microarray expression profiling

Using ten blood samples (5 SZ patients and 5 controls) in microarray profiling, 125 lncRNAs were identified with significantly different expression levels in SZ patients compared with controls (fold change ≥ 2; P<0.05). Of these, 62 lncRNAs were up-regulated and 63 others were down-regulated. The list of the differentially expressed miRNAs identified by microarray analysis is shown in Table 1. In the 125 differentially expressed miRNAs, 5 up-regulated lncRNAs (NONHSAT021545, NONHSAT041499, NONHSAT089447, NONHSAT098126, NONHSAT104778) and 5 down-regulated lncRNAs (ENST00000394742, ENST00000521622, ENST00000563823, TCONS_l2_00021339 and TCONS_l2_00025502) were chosen for further validation in larger sample using the qRT-PCR method (Table 1). These 10 miRNAs were chosen based on the following criteria: miRNAs with higher fold change in microarray results; miRNAs that had been reported; miRNAs that could be detected in every sample.

Comparison of lncRNA expression between SZ patients and controls

As shown in the Table 2, altogether three lncRNAs (NONHSAT089447, NONHSAT021545 and NONHSAT041499) in the 125 differentially expressed lncRNAs (ENST00000394742, ENST00000521622, ENST00000563823, TCONS_l2_00021339 and TCONS_l2_00025502) were chosen for further validation in larger sample using the qRT-PCR method (Table 1). The 10 miRNAs were chosen based on the following criteria: miRNAs with higher fold change in microarray results; miRNAs that had been reported; miRNAs that could be detected in every sample.

LncRNA co-expressed coding genes

We had three differentially expressed lncRNAs (NONHSAT089447, NONHSAT021545 and NONHSAT041499), and correspondingly, we identified 1773 mRNAs co-expressed with NONHSAT021545, 638 miRNAs co-expressed with NONHSAT041499 and 1602 mRNAs co-expressed with NONHSAT089447. There were 89 mRNAs that co-expressed simultaneously with three above-mentioned lncRNAs (Table 3). Figure 1B was the heat maps generated by the 30 most relevant mRNAs expression levels of the three lncRNAs by unsupervised hierarchical clustering analysis.

GO enrichment analysis for lncRNA co-expressed genes

GO biological process enrichment analysis was carried out for those mRNA co-expressed with lncRNAs, and the results suggested that these genes have a wide variety of biological effects associated with signal transduction, multicellular organismal development, cell cycle, cell proliferation, differentiation, apoptosis, and metabolic process, etc. Notably, several important biological processes (pallium development, axon guidance and extension, synaptic transmission, synaptic transmission, learning, memory etc.) played a significant role in brain development and function (Table 4), which may be relevant to the pathophysiology of SZ.

KEGG signal pathway enrichment analysis for lncRNA co-expressed genes

Similarly, the KEGG pathway analysis showed that significant enrichment in 10 pathways related to neuronal brain function, such as ribosome signaling pathway, lysosome signaling pathway, GnRH signaling pathway, mTOR signaling pathway, insulin signaling pathway, apoptosis signaling pathway etc. (Figure 4).

Association analysis between lncRNA and transcription factors

We identified 7 transcription factors that were significantly associated with NONHSAT021545, namely TAF1, USF1, CEBPB, BRCA1, EBF1, ZBTB33 and NFE2, 2 transcription factors that were significantly associated with NONHSAT041499, namely E2F6 and NFE2, and 2 transcription factors that were significantly associated with NONHSAT089447, namely JUND, TBP, TAF1, BATF, ELK4, EBF1 and ZBTB7A. A topographical map of lncRNA, transcriptional factors and target genes was constructed as Figure 5.

Discussion

LncRNA might play a significant and complicated regulating role in gene expression at epigenetic, transcriptional and post-transcriptional levels [18] (2015), exerting important effects upon the onset and development of a great variety of diseases and disorders Zhao et al. [19], Uchida et al. [20], Su et al. [21], potentiating itself to be a new clinical marker and therapeutic target for diagnosis and prognosis. Currently, researches about lncRNA covering a wide range of diseases have been gradually taken off, but not yet in the field of psychiatry [17,22,23]. In our previous study, we found that three lncRNAs, namely NONHSAT089447, NONHSAT021545 and NONHSAT041499, were significantly up-regulated in the peripheral blood mononuclear cells in 5 SZ patients and 5 controls by microarray analysis and PCR verification. In order to further explore the role of lncRNA in the molecular mechanism of SZ, we carried out bioinformatics analysis in this study.
Figure 1. Heat map for NONHSAT021545

Table 3. Co-expressed genes with all three lncRNAs

| Gene 1 | Gene 2 | Gene 3 | Gene 4 | Gene 5 | Gene 6 | Gene 7 | Gene 8 | Gene 9 |
|--------|--------|--------|--------|--------|--------|--------|--------|--------|
| EP0A3  | IL6R   | EP0A4  | PPTC7  | PRELID1| ANKR36 | CT62   | MGEA5  |        |
| ZNF155 | SEL1L3 | MTRF1L | LOC15381| REX01L1| TRERF1 | E1F4G3 | RASGR3 |        |
| SII2D1A| FZD1   | LSM1   | TRPS1  | RD3    | RNF220 | ZNF550 | FAM196B|        |
| CD79A  | IFT46  | SSB    | GCNT2  | COL19A1| PAK1   | RPL26  | IL1RAP |        |
| ARID5B | PCDHB4 | CTNNAA1| ASCC3  | BSDC1  | TRMT5  | ITGA1  | OXCT1  |        |
| KIAA0485| DIAPH3| psTPTE22| FLT3   | SIGLEC5| UPF2   | MRPL9  | RPL35  |        |
| LOC100507650| EYA1| ROS1  | LEUTX | DOK7  | RMS3  | MGCG20647| ANO1  |        |
| MAPK14 | GB3    | MEX3D  | TMEM164| SLC9A1| DISC1  | CCR2   | KCNE1  |        |
| LHFPL1 | GYLTL1B| CDCA7L | PPPP2CB| RPL36A | OR2L3  | FCR1L  | LBH    |        |
| HMGN2  | WDFY3  | LOC10050857| HRNRPAI1L2| KCN15  | RPL37A| GPATCH3| FAM129C|        |
| MCF2   | PET117 | MYL10  | PIK3C2B| RAB21  | FAM190B| RPS19  | FM05   |        |
| AUTS2  |        |        |        |        |        |        |        |        |
 Firstly, we identified the differentially expressed mRNA by microarray analysis, and we further identified the mRNA closely relevant to the differentially expressed lncRNA (NONHSAT089447, NONHSAT021545 and NONHSAT041499) by Pearson association analysis, which numbered in hundred and thousand. This result might suggest that individual lncRNA regulate a multiple target gene, participating a wide range of biological processes. Among them, a total of 89 mRNAs co-expressed with all three aberrant lncRNAs, indicating that they be closely involved into the pathogenesis of SZ.

GO enrichment biological process analysis results demonstrated that mRNA co-expressed with lncRNA implicated a great variety of biological processes, among which there were several ones involving central nervous system, such as neuronal apoptosis and regulation, Ras signaling transduction, lipopolysaccharide reaction, JNK signaling pathway and regulation, stress-related protein kinase signaling pathway and regulation, learning and memory, regulation of synaptic structure and activity, the formation, development, cortical layering, axongensis of neural projection, and so on. These nervous biological processes in turn implicate multiple mechanism of SZ Glantz et al. [24], Stornetta et al. [25], Wischhof et al. [26], possibly in a way regulating multiple downstream gene expression, causing physiopathological changes leading to pathogenesis of SZ.

KEGG signaling pathway enrichment analysis results showed significant enrichment in ribosome pathway, lysosome pathway, Lou Gehrig’s disease pathway, glycolysis/gluconeogenesis, GnRH signaling pathway, hematopoietic cell system, white blood cell subcutaneous...
Figure 3. Heat map for NONHSAT089447

Figure 4. mRNA KEGG pathways with significant enrichment co-expressed with lncRNA

- KEGG signaling pathways with significant enrichment:
  - Ribosome
  - Lysosome
  - Amyotrophic lateral sclerosis
  - Glycolysis/Gluconeogenesis
  - GnRH signaling pathway
  - Hematopoietic cell lineage
  - Leukocyte transendothelial...
  - mTOR signaling pathway
  - Insulin signaling pathway
  - Apoptosis

- -lgp
migration pathway, mTOR signaling pathway, insulin signaling pathway and apoptosis pathway. Among them, the mTOR signaling pathway and insulin signaling pathway demonstrated close involvement with the pathogenesis of SZ. One study indicated that mTOR could suppress the expression of DPYS12, which in turn increases the risk of SZ [17]. Another study showed that elevated activity of mTOR could ameliorate or improve the cognitive disorder of SZ animal model [27]. A systematic review by Guruajan et al. elaborated on the close relationship between mTOR signaling pathway and SZ pathogenesis [28]. On the other hand, the insulin signaling pathway may play a significant role in the brain development and function. Impaired insulin pathway could be observed in SZ patients, and antipsychotics could restore this pathway [29].

Transcription factors are protein molecules with special structure and gene regulation function. They specifically and exclusively bind with certain up-stream sequence at 5’ end of target gene, thus guaranteeing that the target gene expression maintains a certain intensity at a certain time and site. We used graph theory to evaluate the contribution of lncRNA and relevant transcription factors to the interaction map with node frequency, which represented the interaction frequency. A higher node frequency indicates a bigger coverage of biological factors, and the highest node frequency may be the key lncRNA, transcription factor or target gene that exerts the key regulating effect. In Table 3, the node frequencies of NONHSAT021545 and NONHSAT089447 were 254 and 249 respectively, much higher than that of NONHSAT041499, which was 26, suggesting that the first two lncRNAs regulate much more target genes than the third one, thus probably exerting more important biological effects. Of the transcription factors, TAF1, EBF1 and USF1 had the highest node frequency, which were 130, 71 and 51 respectively. Among them, TAF1 Hansen et al. [30] and EBF1 Jajodia et al. [31] have been reported to be closely associated with SZ. Target genes with node frequency higher than 8 included RPL13A, RPL12, RPL10A, RPS2, CASCA, HIST1H4E, PTMA, RPL17, RPL26, RPL3, RPS18, SH2B3, SLC15A4, TPP1 and TRAPP2L, suggesting these genes might play an important role in the pathomechanism of SZ, which warrants further investigation.

Bioinformatics methodology made functional annotation for lncRNA, facilitating efficiently the identification of target genes and signaling pathways from huge amount of microarray analysis results. In this study, we analyzed three lncRNA (NONHSAT089447, NONHSAT021545 and NONHSAT041499) and their co-expressed mRNAs, and found these mRNA-involved GO biological processes and KEGG signaling pathways and made predictions about the transcription factors and target genes implicating these lncRNAs. We will explore further into these data, in a bigger effort to the role of these lncRNA in the pathomechanism of SZ.

References
1. van Os J, Kapur S (2009) Schizophrenia. Lancet 374: 635-645. [Crossref]
2. Fan HM, Sun XY, Niu W, Zhao L, Zhang QL, et al. (2015) Altered microRNA Expression in Peripheral Blood Mononuclear Cells from Young Patients with Schizophrenia. J Mol Neurosci 56: 562-571. [Crossref]
3. Schwarz E, Bahn S (2008) Biomarker discovery in psychiatric disorders. Electrophoresis 29: 2884-2890. [Crossref]
4. Lakhan SE, Kramer A (2009) Schizophrenia genomics and proteomics: are we any closer to biomarker discovery. Behav Brain Funct 5: 2. [Crossref]
5. Pounting CP, Oliver PL, Reik W (2009) Evolution and functions of long noncoding RNAs. Cell 136: 629-641. [Crossref]
6. Gutman M, Rinn JL (2012) Modular regulatory principles of large non-coding RNAs. Nature 482: 339-346. [Crossref]
7. Wu P, Zuo X, Deng H, Liu X, Liu L, et al. (2013) Roles of long noncoding RNAs in brain development, functional diversification and neurodegenerative diseases. Brain Res Bull 97: 69-80. [Crossref]
8. Barry G, Briggs JA, Vanichkina DP, Poth EM, Beveridge NJ, et al. (2014) The long non-coding RNA Gsmafu is acutely regulated in response to neuronal activation and involved in schizophrenia-associated alternative splicing. Mol Psychiatry 19: 486-494. [Crossref]

9. Qureshi IA, Mattick JS, Mehler MF (2010) Long non-coding RNAs in nervous system function and disease. Brain Res 1358: 20-35. [Crossref]

10. Kumaraswamy R, Baetens C, Volkmann I, Maury F, Feitsch J, et al. (2014) Circulating long noncoding RNA, LIPCAR, predicts survival in patients with heart failure. Circ Res 114: 1569-1575. [Crossref]

11. Su W, Xie W, Shang Q, Su B (2015) The Long Noncoding RNA MEG3 Is Downregulated and Inversely Associated with VEGF Levels in Osteoarthritis. Biomed Res Int 2015: 356893. [Crossref]

12. Arisi I, D’Omofo M, Brandi R, Felsani A, Capsoni S, et al. (2011) Gene expression biomarkers in the brain of a mouse model for Alzheimer’s disease: mining of microarray data by logic classification and feature selection. J Alzheimers Dis 24: 721-738. [Crossref]

13. Liu Z, Li X, Sun N, Xu Y, Meng Y, et al. (2014) Microarray profiling and co-expression network analysis of circulating IncRNAs and mRNAs associated with major depressive disorder. PLoS One 9: e93388. [Crossref]

14. Sai Y, Zou Z, Peng K, Dong Z (2012) The Parkinson’s disease-related genes act in mitochondrial homeostasis. Neurosci Biobehav Rev 36: 2034-2043. [Crossref]

15. Wang X, Arai S, Song X, Reichart D, Du K, et al. (2008) Induced ncRNAs allosterically modify RNA-binding proteins in cis to inhibit transcription. Nature 454: 126-130. [Crossref]

16. Mercer TR, Dinger ME, Sunkin SM, Mehler MF, Mattick JS (2008) Specific expression of long noncoding RNAs in the mouse brain. Proc Natl Acad Sci U S A 105: 716-721. [Crossref]

17. Liu Y, Pham X, Zhang L, Chen PL, Burzynski G, et al. (2014) Functional variants in DPYSIL2 sequence increase risk of schizophrenia and suggest a link to mTOR signaling. G3 (Bethesda) 5: 61-72. [Crossref]

18. Guo X, Gao L, Wang Y, Chia DK, Wang T, et al. (2016) Advances in long noncoding RNAs: identification, structure prediction and function annotation. Brief Funct Genomics 15: 38-46. [Crossref]

19. Zhao J, Liu Y, Huang G, Cui P, Zhang W, Zhang Y (2015) Long non-coding RNAs in gastric cancer: versatile mechanisms and potential for clinical translation. Am J Cancer Res 5: 907-927. [Crossref]

20. Uchida S, Dimmeler S (2015) Long noncoding RNAs in cardiovascular diseases. Circ Res 116: 737-750. [Crossref]

21. Su YJ, Yu J, Huang YQ, Yang J (2015) Circulating Long Noncoding RNA as a Potential Target for Prostate Cancer. Int J Mol Sci 16: 13322-13338. [Crossref]

22. Spadaro PA, Flavell CR, Widagdo J, Ramu VS, Troup M, et al. (2015) Long Noncoding RNA-Directed Epigenetic Regulation of Gene Expression Is Associated with Anxiety-like Behavior in Mice. Biol Psychiatry 78: 848-859. [Crossref]

23. Ziats MN, Rennert OM (2013) Aberrant expression of long noncoding RNAs in autistic brain. J Mol Neurosci 49: 589-593. [Crossref]

24. Glantz LA, Gilmore JH, Lieberman JA, Jankog LF (2006) Apoptotic mechanisms and the synaptic pathology of schizophrenia. Schizophr Res 81: 47-63. [Crossref]

25. Stornetta RL, Zhu JJ (2011) Ras and Rap signaling in synaptic plasticity and mental disorders. Neuroscientist 17: 54-78. [Crossref]

26. Wischhof L, Irmack E, Osorio C, Koch M (2015) Prenatal LPS-exposure—a neurodevelopmental rat model of schizophrenia—differentially affects cognitive functions, myelination and parvalbumin expression in male and female offspring. Prog Neuropsychopharmacol Biol Psychiatry 57: 17-30. [Crossref]

27. Meffre J, Chaumont-Dubel S, Mannoury, Cour C, Loiseau F, et al (2012) 5-HT1A receptor recruitment of mTOR as a mechanism for perturbed cognition in schizophrenia. EMBO Mol Med 4: 1043-1056. [Crossref]

28. Gururajan A, van den Buuse M (2014) Is the mTOR-signalling cascade disrupted in schizophrenia? J Neurochem 129: 377-387. [Crossref]

29. Gorgis RR, Javitch JA, Lieberman JA (2008) Antipsychotic drug mechanisms: links between therapeutic effects, metabolic side effects and the insulin signaling pathway. Mol Psychiatry 13: 918-929. [Crossref]

30. Hansen T, Olsen L, Linow M, Jakobsen KD, Ullum H, et al. (2007) Brain expressed microRNAs implicated in schizophrenia etiology. PLoS One e873. [Crossref]

31. Jajodia A, Kaur H, Kumari K, Gupta M, Baghel R, et al. (2015) Evidence for schizophrenia susceptibility alleles in the Indian population: An association of neurodevelopmental genes in case-control and familial samples. Schizophr Res 162: 112-117. [Crossref]

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