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Transcranial Magnetic Stimulation for Schizophrenia: A Meta-Analysis

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ABSTRACT

Background: Schizophrenia is a significant cause of morbidity, and current biologic treatments often fail to achieve remission. Repeated transcranial magnetic stimulation (rTMS) is a non-invasive neuromodulation therapy approved for major depression. Peer-reviewed literature suggests that rTMS may have efficacy for psychosis as well as negative and cognitive symptoms; however, holistic data regarding the use of rTMS for schizophrenia remains unclear.

Objective: We aim to synthesize published data of rTMS efficacy in treating schizophrenia and evaluate the most efficacious treatment parameters.

Methods: A meta-analysis was performed evaluating mean weighted effect sizes (Cohen's d) and heterogeneity (Cochran's I2).

Results: 24 studies were included for analysis (N=4091). rTMS demonstrated greater effect sizes over sham in Positive and Negative Syndrome Scale (PANSS) negative (d=0.40, p=0.007 I2=59), PANSS general (d=0.31, p=0.004, I2=0) and Global Assessment of Functioning (GAF) (d=0.470, p=0.020, I2=58.2) scores. rTMS also demonstrated significant effect sizes over sham in PANSS positive (d=0.207, p=0.017, I2=20.2) and MADRS (d=0.457, p=0.023, I2=54.1) Sub-group analyses indicated that the stimulation location and frequency did not statistically influence efficacy.

Conclusion: rTMS may have benefits for treating schizophrenia, particularly in reducing negative symptoms when targeting the dorsal lateral prefrontal cortex (DLPFC) with high frequency stimulation (≥ 10 Hz). There was no evidence to support the efficacy of rTMS on audiovisual hallucinations. Further large-scale clinical trials are necessary to verify these findings and evaluate the durability of treatment effects, as there is limited long-term outcome data for the use of TMS for schizophrenia.

Keywords: TMS; Neuromodulation; Schizophrenia; Meta-analysis review

INTRODUCTION

Schizophrenia remains one of the most poorly controlled psychiatric diseases. While pharmacologic treatment has focused on targeting the positive symptoms of schizophrenia, few treatment options exist for the negative symptoms. Severity of neg-

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ative symptoms has been demonstrated to be closely correlated with quality of life and functional outcomes [1]. Even with an international prevalence of approximately 1%, schizophrenia exerts a large cost on both healthcare and social systems, primarily through the loss of work productivity. Only 10%-20% of individuals are able to hold a job, representing a significant economic loss, estimated at $ 155.7 billion with 38% of that total attributed to unemployment in the U.S.A and subsequent financial burden on the patient's caregivers [2-4]. Moreover, individuals with schizophrenia end up destitute at a much higher rate than the general population [5]. Thus, any treatment modalities that improve symptoms, more specifically negative and cognitive symptoms, could be of significant benefit and greatly reduce the morbidity of the disease.

Negative symptoms and cognitive impairment from psychosis are major contributors to social and functional debilitation for many patients suffering from schizophrenia. Unfortunately, antipsychotic medications have limited efficacy in these Research Domain Criteria (RDoc) constructs, suggesting a need for more treatment options to supplement a more holistic approach towards therapy [6]. One avenue being explored is the use of non-invasive brain stimulation (NIBS) which has been studied primarily in treatment-resistant depression. NIBS, specifically electroconvulsive therapy (ECT), has been a staple of psychiatric treatment for many decades with more focused modalities, such as direct current stimulation (DCS) and transcranial magnetic stimulation (TMS), gaining clinical favor over recent years due to less adverse effects and greater ease of implementation in the outpatient settings [7,8]. TMS applies a magnetic field that can penetrate the skull and induces changes in neuronal activity as well as plasticity at the cortical level through both immediate and long-term potentiation and/or depression [9]. It has been demonstrated that low frequencies (1 Hz or less) reduce cortical activity, while high frequencies (>10 Hz) increase cortical activity [10].

In schizophrenia, hyperactivity of the auditory cortex occurs during auditory hallucinations [11], while hypo-functioning of the dorsal lateral prefrontal cortex (DLPFC) has been implicated in the pathogenesis of negative symptoms [12]. When targeting positive symptoms of schizophrenia, the auditory cortex has been targeted at low frequencies (1 Hz) to reduce cortical activity and induce long-term depression (LTD). In contrast, 10 Hz (or more) has been used over the DLPFC to increase cortical excitation and induce long-term potentiation (LTP) to attempt to alleviate negative symptoms. These long-term changes in potentiation have been postulated to modulate glutamate receptors, such as N-Methyl-D-aspartic acid (NMDA) and α-amino-3-hydroxy-5-methyl-4-isoxazoleproprionic acid (AMPA) receptors [13].

Multiple clinical trials have been conducted over the last decade utilizing TMS for the treatment of schizophrenia. While the parameters of location and frequency for each respective category of symptoms (e.g., 10 Hz over the DLPFC for negative symptoms and 1 Hz over the temporoparietal junction (TPJ) for positive symptoms) have remained relatively consistent, the length of treatment, total stimulation, type of sham, assessment measures, and patient characteristics are heterogeneous from study to study, leading to conflicting results at times [14]. Recent reviews of the literature have been unable to definitively support or refute the use of TMS in the treatment of schizophrenia, due in part to this heterogeneity in treatment protocols and outcome measures.

In this study, we aim to provide a comprehensive review that synthesizes the published data regarding the efficacy of TMS for schizophrenia and provide sub-group analyses to determine the ideal stimulation parameters for the individual treatment of negative and positive symptoms.

METHODS

This meta-analysis was performed in accordance with the Preferred Reporting Items for Systematic reviews and Meta-Analyses statement [15].

Literature Search and Study Selection

An online search was conducted reviewing PubMed, Google Scholars, and clinicaltrials.gov using the terms "transcranial magnetic stimulation," "TMS," "schizophrenia," "psychosis," and "psychotic disorders". There were no restrictions placed upon date of publication or language. The last database search was performed in January 2019. Literature was screened by two independent evaluators and selected based on inclusion/exclusion criteria.

Inclusion Criteria

Randomized, double-blind, sham-controlled trials using TMS as an adjunct to antipsychotic treatment, subjects were diagnosed with schizophrenia based on either the Diagnostic or Statistical Manual of Mental Disorders (DSM-III, DSM-IIIR, DSM-IV, DSM-IV-TR, and DSM-V) or International Classification of Diseases (ICD 9 or 10).

Exclusion Criteria

Data provided in the study were unclear and/or inadequate for proper statistical analysis.

Study data overlapped with at least one other study containing a larger patient sample size.

Data Collection

Study data were independently verified by the investigators and all study inclusion and exclusion criteria were determined by consensus.

Data Items

Outcomes examined include (in alphabetical order): Auditory Hallucination Rating Scale (AHRS), Brief Psychiatric Rating Scale (BPRS), Clinical Global Impression-Improvement (CGI-I), Clinical Global Impression-Severity (CGI-S), Global Assessment of Functioning (GAF), Montgomery-Asnerg Depression Rating Scale (MADRS), Positive and Negative Syndrome Scale (PANSS) negative, Positive and Negative Syndrome Scale (PANSS) positive, Positive and Negative Syndrome Scale (PANSS) total, Scale for the Assessment of Negative Symptoms (SANS), Psychotic Symptom Rating Scale (PSYRATS), Scale for the Assessment of Positive Symptoms (SAPS), and Trail Making Test-Part A (TMT-A). Of these, we included only AHRS, GAF, MADRS, PANSS negative, PANSS positive, PANSS general, PANSS total, and SANS due to

their having 3 or more studies available for analysis that met our inclusion criteria.

Statistical Analysis

To derive the outcome variable, we used reported mean differences, F-statistics, and t-statistics to calculate the standardized mean difference (Cohen's d) for each study that did not directly report it. For each reported outcome, we conducted separate meta-analyses, using a random effects model. We used I2 statistics to evaluate for heterogeneity, or the percentage of variance in a meta-analysis that is attributable to variations in study design outside of random chance. We assessed publication bias using Funnel plots and tested for possible small study effects using Egger's test. Galbraith plots were generated to further evaluate heterogeneity.

We defined two possible factors, location of stimulation (right/left/bilateral OR temporoparietal vs. other) and frequency (<10 Hz vs. =>10 Hz OR<=1 Hz vs. >1 Hz) that vary between studies and could lead to heterogeneity. To further describe possible heterogeneity, we conducted stratified random effects meta regressions for a subset of outcomes (PANSS positive, PANSS negative, PANSS total) as these were the most often reported results and thus there were sufficient studies to allow for stratified analysis. When the analyses showed little difference in effect estimates across strata (assessed by overlapping confidence intervals), we presented the un-stratified meta-analyses. We used Stata 15 (StataCorp, College Station, TX) to conduct all data management and analyses. A confidence interval which did not include 0 (the null value) was deemed to be statistically significant.

RESULTS

Literature Search

39 studies were assessed for eligibility, and 24 of the 39 studies then were included in accordance with our inclusion and exclusion criteria [16-40]. 14 of the studies were excluded from the meta-analysis because of missing outcome data that did not allow for calculation of an effect size, and one was excluded because it did not compare TMS treatment to sham TMS (**Figure 1**).

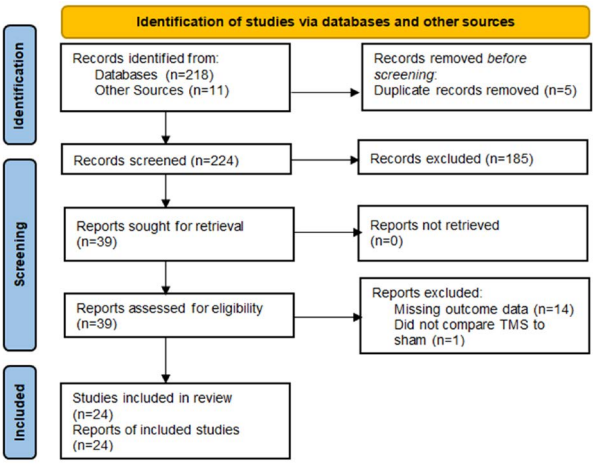

Figure 1: Modified PRISMA 2020 flow diagram for new systematic reviews and meta-analysis

PANSS Negative

TMS augmentation across 13 studies (N=555) showed statistically significant improvement in reducing PANSS negative symptom scores compared to sham with a medium effect size of d=0.40 (p=0.007). There was also moderate variation in outcomes across studies (I^2=59%) and a potential publication bias towards positive treatment outcomes. Egger's test revealed no small study effects.

PANSS Positive

TMS augmentation across 16 studies (N=760) showed a small but statistically significant effect on PANSS positive symptom scores compared to sham with d=0.21 (p=0.017). The included studies demonstrated some variation (I2=20.2%) in outcomes across studies, and there may also be publication bias towards positive treatment outcomes.

PANSS Total

TMS augmentation across 8 studies (N=476) showed no statistically significant effects on PANSS total symptom scores compared to sham with d=0.14 (p=0.261). The included studies had some variation in outcomes across studies (I2=33.2%) and there may also be publication bias towards positive treatment outcomes.

PANSS General

TMS augmentation across 8 studies (N=373) showed statistically significant effects on PANSS general scores compared to sham with d=0.31 (p=0.004). The included studies had minimal variation in outcomes across studies (I2=0%) and there may be publication bias towards positive treatment outcomes. Egger's test for small study effects was nonsignificant.

AHRS

TMS augmentation across 10 studies (N=320) did not show significant improvement in reducing AHRS scores compared to sham, with an effect size of d=0.234 (p=0.312). The included studies had significant variation in outcomes across studies (I2=74.5%) and there may also be publication bias towards positive treatment outcomes.

SANS

TMS augmentation across 5 studies (N=221) showed a significant moderate effect on SANS scores compared to sham with d=0.396 (p=0.004). The included studies did not have significant variation in outcomes across studies (I2=0%), however, there was some evidence of publication bias towards positive treatment outcomes.

GAF

TMS augmentation across 4 studies (N=294) showed a statistically significant effect in increasing GAF scores compared to sham with a medium effect size of d=0.470 (p=0.020). The included studies demonstrated moderate variation in outcomes across studies (I2=58.2%) and there may also be publication bias towards positive treatment outcomes.

MADRS

TMS augmentation across 4 studies (N=282) demonstrated a statistically significant effect in improving MADRS scores compared to sham with a medium effect size of d=0.457 (p=0.023). The included studies demonstrated moderate variation in outcomes across studies (I2=54.1%) and there may also be publication bias towards positive treatment outcomes.

rTMS Moderator Effects

Stratified random effects meta regression analysis for factors of:(1) location of stimulation (right/left/bilateral dorsal lateral prefrontal cortex vs. temporoparietal and other) and (2) frequency (<10 Hz vs. =>10 Hz OR<=1 Hz vs. >1 Hz) did not demonstrate a statistically significant impact on PANSS positive, PANSS negative, or PANSS total scores (data not shown). However, the reduction in PANSS score was greater in the higher frequency rates (10 Hz) or when targeting the DLPFC.

DISCUSSION

Based on our meta-analysis examining the efficacy of TMS augmentation for the treatment of schizophrenia, we found that TMS was favored over sham in multiple treatment outcome domains. The majority of the benefits appears to be weighted towards improving negative symptoms compared to positive symptoms, given the greater effect size seen in reducing PANSS negative scores (d=0.40) compared to reducing PANSS positive scores (d=0.21). There was significant heterogeneity across studies that measured PANSS negative scores (I2=59%) that may compromise our ability to draw conclusions from this piece of evidence, as studies that measured PANSS negative scores varied in their selection of stimulation target and stimulation frequency. Additional outcomes including AHRS, CGI, PANSS total did not demonstrate statistically significant effects between treatment and sham groups.

Currently, it remains unclear how sustainable the treatment effects are, as most TMS for schizophrenia studies have short treatment durations with limited long term follow up data. Studies of TMS treatment in other illnesses like depression have demonstrated sustained benefits for several months, with extension of treatment benefits with maintenance treatment. Moreover, Li et al's 2016 study of 47 participants with schizophrenia demonstrated a delayed effect of rTMS on negative symptoms, finding that SANS scores had no change at 4 weeks of treatment but were significantly improved compared to sham by 8 weeks of treatment. Like target, frequency and pattern of stimulation, duration of stimulation treatment is yet another variable that needs further investigation to determine optimal standardized treatment protocol. Schizophrenia is a highly heterogenous disorder with symptom profiles that vary between patients; therefore, it may benefit future researchers to focus on standardizing treatment parameters for specific outcome measures relevant to schizophrenia, rather than attempting to find one optimal standardized treatment for schizophrenia as a whole.

The current sub-group analysis sought to elucidate the optimal treatment parameters based on existing data. We analyzed location of stimulation and frequency of stimulation. Current data from clinical studies suggest that higher frequency DLPFC stimulation demonstrated greater effect sizes for the improvement of negative symptoms while low frequency TPJ stimulation demonstrated greater effect sizes for auditory hallucinations, but these were not statistically significant. However, this data is limited by the heterogeneity of treatment parameters with little standardization of protocols. For instance, the duration of treatment ranged from subjects receiving 20 sessions to 100 sessions of TMS (the average study had only 20 sessions). To date, no clinical trial has provided direct comparison of varying treatment parameters on outcome effects in the use of TMS augmentation for schizophrenia. Another significant limitation is the lack of available follow up data. The lack of longitudinal data leads to unclear sustainability of treatment effects and impacts clinical utility, though studies of the impact of neuro-modulation on network dynamics have suggested that TMS could potentially induce sustained neurologic changes for up to 6 months.

CONCLUSION

Current data suggest there may be clinical utility in using low frequency TPJ TMS for short-term treatment of positive symptoms and high frequency DLPFC TMS for short-term treatment of negative symptoms. It remains to be seen, however, whether TMS can provide sustained improvement in the treatment of schizophrenia beyond the acute to subacute treatment period. Studies of the efficacy of TMS for schizophrenia that follow up for 12 months or more are needed in order to properly evaluate the durability of treatment effects. In addition, our results should be interpreted with caution due to the substantial heterogeneity present in the results of many studies included in this meta-analysis, as well as the possibility that there was a publication bias toward positive outcomes. Future clinical trials should identify informed treatment outcomes and appropriate parameters including targeted location, frequency of stimulation, and total stimulation on impact of outcome changes. The development of a more rigorously standardized protocol for the use of TMS in schizophrenia could aid in clarifying the utility of the procedure for this indication.

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REFERENCES

1. Fervaha G, Foussias G, Agid O, Remington G (2014) Impact of primary negative symptoms on functional outcomes in schizophrenia. Eur Psychiatry. 29(7):449-55.

2. Sarkar S, Hillner K, Velligan DI (2015) Conceptualization and treatment of negative symptoms in schizophrenia. World J Psychiatry. 22;5(4):352-61.

3. Rössler W, Salize HJ, van Os J, Riecher-Rössler A (2005) Size of burden of schizophrenia and psychotic disorders. Eur Neuropsychopharmacol. 15(4):399-409.

4. Cloutier M, Aigbogun MS, Guerin A, Nitulescu R, Ramanakumar AV, et al. (2016) The economic burden of schizophrenia in the United States in 2013. J Clin Psychiatry. 77(6):764-71.

5. Fazel S, Khosla V, Doll H, Geddes J (2008) The prevalence of mental disorders among the homeless in western countries: Systematic review and meta-regression analysis. PLoS Med. 5(12):e225.

6. Carpenter WT Jr, Buchanan RW (1994) Schizophrenia. N Engl J Med. 330(10):681-90.

7. Boes AD, Kelly MS, Trapp NT, Stern AP, Press DZ, et al. (2018) Noninvasive brain stimulation: Challenges and opportunities for a new clinical specialty. J Neuropsychiatry Clin Neurosci. 70:103514.

8. Cocchi L, Zalesky A, Nott Z, Whybird G, Fitzgerald PB, et al. (2018) Transcranial magnetic stimulation in obsessive-compulsive disorder: A focus on network mechanisms and state dependence. Neuroimage Clin. 19:661-674.

9. Kozyrev V, Staadt R, Eysel UT, Jancke D (2018) TMS-induced neuronal plasticity enables targeted remodeling of visual cortical maps. Proc Natl Acad Sci U S A. 115(25):6476-6481.

10. Speer AM, Kimbrell TA, Wassermann EM, D Repella J, Willis MW, et al. (2000) Opposite effects of high and low frequency rTMS on regional brain activity in depressed patients. Biol Psychiatry. 48(12):1133-41.

11. Silbersweig DA, Stern E, Frith C, Cahill C, Holmes A, et al. (1995) A functional neuroanatomy of hallucinations in schizophrenia. Nature. 378(6553):176-9.

12. Wolkin A, Sanfilipo M, Wolf AP, Angrist B, Brodie JD, et al. (1992) Negative symptoms and hypofrontality in chronic schizophrenia. Arch Gen Psychiatry. 49(12):959-65.

13. Huerta PT, Volpe BT (2009) Transcranial magnetic stimulation, synaptic plasticity and network oscillations. J Neuroeng Rehabil. 2;6:7.

14. Nieuwdorp W, Koops S, Somers M, Sommer IE (2015) Transcranial magnetic stimulation, transcranial direct current stimulation and electroconvulsive therapy for medication-resistant psychosis of schizophrenia. Curr Opin Psychiatry. 28(3):222-228.

15. Moher D, Liberati A, Tetzlaff J, Altman DG; PRISMA Group (2009) Preferred reporting items for systematic reviews and meta-analyses: The PRISMA statement. PLoS Med. 6(7):e1000097.

16. Bagati D, Nizamie SH, Prakash R (2009) Effect of augmentatory repetitive transcranial magnetic stimulation on auditory hallucinations in schizophrenia: Randomized controlled study. Aust N Z J Psychiatry. 43(4):386-392.

17. Barr MS, Farzan F, Tran LC, Fitzgerald PB, Daskalakis ZJ (2012) A randomized controlled trial of sequentially bilateral prefrontal cortex repetitive transcranial magnetic stimulation in the treatment of negative symptoms in schizophrenia. Brain Stimul. 5(3):337-346.

18. Blumberger DM, Christensen BK, Zipursky RB, Moller B, Chen R, et al. (2012) MRI-targeted repetitive transcranial magnetic stimulation of Heschl's gyrus for refractory auditory hallucinations. Brain Stimul. 5(4):577-585.

19. Brunelin J, Poulet E, Bediou B, Kallel L, Dalery J, et al. Low frequency repetitive transcranial magnetic stimulation improves source monitoring deficit in hallucinating patients with schizophrenia. Schizophr Res. 81(1):41-45.

20. Cordes J, Thünker J, Agelink MW, Arends M, Mobascher A, et al. (2010) Effects of 10 Hz repetitive transcranial magnetic stimulation (rTMS) on clinical global impression in chronic schizophrenia. Psychiatry Res. 177(1-2):32-36.

21. Dlabac-de LJJ, Bais L, van EFD (2015) Efficacy of bilateral repetitive transcranial magnetic stimulation for negative symptoms of schizophrenia: Results of a multicenter double-blind randomized controlled trial. Psychol Med. 45(6):1263-1275.

22. Fitzgerald PB, Herring S, Hoy K (2008) A study of the effectiveness of bilateral transcranial magnetic stimulation in the treatment of the negative symptoms of schizophrenia. Brain Stimul. 1(1):27-32.

23. Garg S, Sinha VK, Tikka SK, Mishra P, Goyal N (2016) The efficacy of cerebellar vermal deep high frequency (theta range) repetitive transcranial magnetic stimulation (rTMS) in schizophrenia: A randomized rater blind-sham controlled study. Psychiatry Res. 243:413-420.

24. Goyal N, Nizamie SH, Desarkar P (2007) Efficacy of adjuvant high frequency repetitive transcranial magnetic stimulation on negative and positive symptoms of schizophrenia: Preliminary results of a double-blind sham-controlled study. J Neuropsychiatry Clin Neurosci. 19(4):464-467.

25. Hajak G, Marienhagen J, Langguth B, Werner S, Binder H, et al (2004) High-frequency repetitive transcranial magnetic stimulation in schizophrenia: A combined treatment and neuroimaging study. Psychol Med. 34(7):1157-1163.

26. Hasan A, Wobrock T, Guse B(2017) . Structural brain changes are associated with response of negative symptoms to prefrontal repetitive transcranial magnetic stimulation in patients with schizophrenia. Mol Psychiatry. 22(6):857-864.

27. Hoffman RE, Gueorguieva R, Hawkins KA (2005) Temporoparietal transcranial magnetic stimulation for auditory hallucinations: Safety, efficacy and moderators in a 50 patient sample. Biol Psychiatry. 58(2):97-104.

28. Holi MM, Eronen M, Toivonen K, Toivonen P, Marttunen M,

et al(2004) Left prefrontal repetitive transcranial magnetic stimulation in schizophrenia. Schizophr Bull. 30(2):429-434.

29. Klirova M, Horacek J, Novak T (2013) Individualized rTMS neuronavigated according to regional brain metabolism ((18)FGD PET) has better treatment effects on auditory hallucinations than standard positioning of rTMS: A double-blind, sham-controlled study. Eur Arch Psychiatry Clin Neurosci. 263(6):475-484.
30. Kimura H, Kanahara N, Takase M, Yoshida T, Watanabe H (2016) A randomized, sham-controlled study of high frequency rTMS for auditory hallucination in schizophrenia. Psychiatry Res. 241:190-194.
31. Klein E, Kolsky Y, Puyerovsky M, Koren D, Chistyakov A (1999) Right prefrontal slow repetitive transcranial magnetic stimulation in schizophrenia: A double-blind sham-controlled pilot study. Biol Psychiatry. 46(10):1451-1454.
32. Koops S, van Dellen E, Schutte MJ, Nieuwdorp W, Neggers SF (2016) Theta Burst Transcranial Magnetic Stimulation for Auditory Verbal Hallucinations: Negative Findings From a Double-Blind-Randomized Trial. Schizophr Bull. 42(1):250-257.
33. Mogg A, Purvis R, Eranti S (2007) Repetitive transcranial magnetic stimulation for negative symptoms of schizophrenia: A randomized controlled pilot study. Schizophr Res. 93(1-3):221-228.
34. Paillère-Martinot ML, Galinowski A, Plaze M (2017) Active and placebo transcranial magnetic stimulation effects on external and internal auditory hallucinations of schizophrenia. Acta Psychiatr Scand. 135(3):228-238.
35. Poulet E, Brunelin J, Bediou B (2005) Slow transcranial magnetic stimulation can rapidly reduce resistant auditory hallucinations in schizophrenia. Biol Psychiatry. 57(2):188-191.
36. Quan WX, Zhu XL, Qiao H (2015) . The effects of high-frequency repetitive transcranial magnetic stimulation (rTMS) on negative symptoms of schizophrenia and the follow-up study. Neurosci Lett. 584:197-201.
37. Slotema CW, Blom JD, de Weijer AD (2011) Can low-frequency repetitive transcranial magnetic stimulation really relieve medication-resistant auditory verbal hallucinations? Negative results from a large randomized controlled trial. Biol Psychiatry. 69(5):450-456.
38. Wobrock T, Guse B, Cordes J (2015) Left prefrontal high-frequency repetitive transcranial magnetic stimulation for the treatment of schizophrenia with predominant negative symptoms: A sham-controlled, randomized multicenter trial. Biol Psychiatry. 77(11):979-988.
39. Wölwer W, Lowe A, Brinkmeyer J (2014) Repetitive transcranial magnetic stimulation (rTMS) improves facial affect recognition in schizophrenia. Brain Stimul. 2014;7(4):559-563.
40. Dougall N, Maayan N, Soares-Weiser K, McDermott LM, McIntosh A (2015) Transcranial Magnetic Stimulation for Schizophrenia. Schizophr Bull. 41(6):1220-2.