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TRANSCRANIAL MAGNETIC STIMULATION (TMS) IN OBSESSIVE-COMPULSIVE DISORDER: CURRENT EVIDENCE

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ABSTRACT

Objective. Obsessive-Compulsive Disorder (OCD) is a chronic psychiatric condition characterized by recurring intrusive thoughts and repetitive behaviors linked to dysfunction within the Cortico-Striato-Thalamo-Cortical (CSTC) circuits. Given that standard pharmacological and psychological interventions are ineffective for a significant portion of patients, there is a necessity for effective alternative neuromodulation treatments.
Aim. This review aims to synthesize current evidence regarding the neurobiological rationale, clinical safety, and utility of Transcranial Magnetic Stimulation (TMS), particularly in treatment-resistant OCD.
Methods. Data were collected through a systematic review of scientific databases (PubMed, Scopus, Google Scholar) focusing on TMS protocols for OCD. The findings were subjected to a qualitative synthesis, focusing on target efficacy and safety profiles.
Findings. TMS is confirmed as a safe, well-tolerated, and effective adjunctive treatment. Deep TMS (dTMS) targeting the medial prefrontal cortex (mPFC) and anterior cingulate cortex (ACC) is the most validated protocol, demonstrating clinical superiority over sham and achieving FDA approval. Inhibitory protocols targeting the Supplementary Motor Area (SMA) also show promise. The primary challenge is methodological heterogeneity across studies.
Conclusions. TMS offers a significant, non-invasive alternative for tr-OCD. Future research must prioritize the standardization of protocols and the development of personalized TMS strategies based on individual neuroimaging data to ensure sustained long-term benefits.

KEYWORDS

Transcranial Magnetic Stimulation, Obsessive-Compulsive Disorder, Neuromodulation, Psychiatry

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1. Introduction

Obsessive-compulsive disorder (OCD) is a chronic psychiatric disorder with an occurrence of 2-3% in the population(Heinzel et al., 2021). It is mainly characterized by recurring intrusive and unwanted thoughts and related time-consuming repetitive behaviours that cause functional impairment, disability and decreased quality of a patient's life. The pathogenesis of OCD is complex, typically tied to neurobiological, immunological, behavioral, environmental and genetic factors(Caykoylu et al., 2022; Piasek et al., 2023). The neurobiological thesis points to the role of neurotransmitters and the dysfunction within the cortico-striato-thalamo-cortical (CSTC) neural circuits alongside the increased activation of the anterior cingulate cortex (ACC), orbitofrontal cortex (OFC), putamen, caudate nucleus, thalamus and many more shown by functional imaging studies(Ozer et al., 2024).

The main treatment method for patients with OCD includes antidepressant medications in combination with cognitive-behavioral therapy (CBT), however only 40-60% of patients respond to pharmacotherapy or psychotherapy(Beaglehole et al., 2025; Ozer et al., 2024). Studies have indicated that transcranial magnetic stimulation (TMS) applied to the dysfunctional or increasingly activated structures of the brain reduces OCD symptoms in patients with treatment-resistant OCD(Jiang et al., 2023; Postma et al., 2025).

The purpose of this review paper is to summarize and compare information on TMS and investigate the evidence on its utility in OCD treatment, as neuromodulation is a rapidly developing area of research in psychiatry.

1.1. Research Objective.

The aim of this systematic review is to analyze the role of TMS in a treatment of OCD, as suggested by the title.

2. Methodology

Data for this review were gathered through a systematic search across major scientific databases, including PubMed, Scopus and Google Scholar. The search strategy employed combined keywords related to the subject matter (e.g., Transcranial Magnetic Stimulation, Deep TMS, OCD, CSTC, Efficacy, Safety). Clinical trials and meta-analyses published in English focusing on TMS protocols (rTMS and dTMS) targeting the SMA/preSMA, DLPFC, OFC, and mPFC/ACC were selected for inclusion. The collected clinical data, such as protocol efficacy, response rates, and adverse events, were subjected to a qualitative synthesis. As this study constitutes a narrative review, no de novo statistical analysis was conducted on individual patient data; instead, the focus was on synthesizing and comparing the statistical findings and conclusions reported in the original publications.

2.1. AI.

AI was utilized for text analysis and refining the academic language of the manuscript. All AI tools were used strictly as instruments under human supervision.

3. Research results

3.1. Principles of TMS

Repetitive TMS (rTMS) is a noninvasive technique that utilizes ferromagnetic coils creating rapidly changing magnetic fields and inducing neuronal depolarization. The electric pulses can have various frequencies, causing change in neuronal excitability in targeted cortical regions(Cowey, 2005; Frid et al., 2023). rTMS also has the potential to restore alternated networks between brain regions in OCD and other anxiety disorders(Postma et al., 2025).

Protocols of rTMS treatment differ in frequency, number of sessions and number of pulses per session. Low-frequency (1 Hz and less) rTMS decreases neuronal excitability, inhibiting areas such as dorsolateral prefrontal cortex (DLPFC) and orbitofrontal cortex, whereas high-frequency (5 Hz and more) rTMS stimulates neurones and increases excitability in ACC and DLPFC(Chou et al., 2022; Conelea et al., 2024; Ji et al., 2021).

3.2. Neurobiological Rationale for TMS in OCD

Etiology of OCD can be correlated with abnormalities concerning sensorimotor network that includes supplementary motor area (SMA) which might be responsible for compulsive behavior. Studies suggest that patients with OCD present changes in functional connectivity between SMA and other regions of the brain(Ruan et al., 2025; Tomiyama et al., 2022), and patients treated with low-frequency rTMS targeted at SMA show 25-30% reduction of compulsions in comparison to the control group(Mantovani et al., 2013). Dysfunctions of the orbitofrontal cortex and DLPFC are also associated with OCD symptoms, and their neuronal inhibition results in reduction of compulsive behaviors(Chou et al., 2022; Conelea et al., 2024; Tzirini et al., 2022).

3.3. Clinical Evidence

3.3.1. SMA stimulation

The studies on rTMS targeted at SMA and its anterior part, presupplementary motor area (preSMA) indicate that the effectiveness of the method depends on neurobiological correlates of network activity as well as individual patterns of functional connectivity(Ji et al., 2021; Postma et al., 2025). A study by Postma et al. has shown that the clinical improvement after rTMS combined with exposure and response prevention (a type of cognitive-behavioral therapy) was linked to decrease of hyperactivation in areas associated with error processing and a modification of amygdala connectivity in response inhibition networks. The authors suggest that individuals with baseline pre-SMA hyperactivity or impaired inhibition may respond best to stimulation of networks associated with it(Postma et al., 2025). The effectiveness of a precisely targeted stimulation has been confirmed in a study utilizing personalized subthalamic nucleus-preSMA connectivity maps, where low-frequency rTMS significantly reduced the severity of OCD symptoms and clinical improvement was associated with a decrease in connectivity strength in the target network(Ji et al., 2021). These results are also supported by a meta-analysis suggesting that low-frequency SMA stimulation may be one of the most effective rTMS techniques used in OCD treatment(Rehn et al., 2018). Additional articles indicate that the SMA and right DLPFC are key nodes of the response inhibition network in OCD, characterized by hyperactivity that can be modulated by inhibitory low-frequency rTMS(Chou et al., 2022). According to previously obtained neuroimaging data, the preSMA is overreactive in both OCD patients and their healthy relatives, suggesting

that it represents a marker of impaired inhibitory control(Tzirini et al., 2022). Excessive activity of preSMA and its connections with the dorsal stratum may promote the dominance of habitual behavior in OCD. Pilot studies have shown that continuous theta burst stimulation (cTBS), a type of low-frequency rTMS, targeted at preSMA can cause decrease in both compulsions and habit circuitry(Conelea et al., 2024).

3.3.2. OFC stimulation

OFC plays a pivotal role in reward system, decision-making and inhibition of maladaptive behaviors, and its dysfunction is well documented in OCD research(Tzirini et al., 2022). OFC is a promising target for neuromodulation because it is closely linked to systems controlling habitual behavior and overactive SMA-putamen loop(Gautam et al., 2025). Neuroimaging studies indicate significant OFC hyperactivity both at rest and during symptom provocation, as well as decreased reactivity during reinforcement reversal tasks; these changes normalize after effective rTMS treatment leading to reduced OCD symptoms(Gautam et al., 2025; Tzirini et al., 2022). However, the efficacy of OFC stimulation remains limited and inconclusive. Clinical studies, including the first randomized trials using cTBS over the right OFC, failed to demonstrate significant reductions in OCD symptoms, although improvements were noted in comorbid depressive symptoms, and the procedure was well tolerated - which was predictable due to the use of the method in the treatment of depression(Kowalczyk et al., 2023; Liu et al., 2021). Furthermore, technical limitations, such as the OFC's proximity to the brow ridges and the risk of discomfort during stimulation, make precise application of TMS difficult. Based on available data, the SMA and pre-SMA remain more promising targets for neuromodulation in OCD, demonstrating greater efficacy and better treatment tolerance(Guo et al., 2022).

3.3.3. DLPFC stimulation

DLPFC is a key target of rTMS in OCD treatment, serving a central role in executive control and repetitive actions(Tzirini et al., 2022). Reduced DLPFC reactivity during planning tasks is observed in OCD patients, reflecting dysfunction of CSTC circuits(Conelea et al., 2024; Tzirini et al., 2022). The aim of DLPFC stimulation is to modulate these dysfunctional circuits to restore balance in neural networks(Chou et al., 2022; Conelea et al., 2024).

3.3.4. Deep TMS (dTMS)

dTMS is an advanced neuromodulation technique utilizing specially designed H-coils (e.g., the H7 coil), which allow for the induction of neuronal depolarization in deeper and broader cortical regions (Roth et al., 2021; Silveira et al., 2022). In the treatment of OCD, the H7 coil is designed to target neural networks in the medial prefrontal cortex (mPFC) and the ACC (especially the dorsal ACC – dACC)(Carmi et al., 2018; Roth et al., 2021; Silveira et al., 2022).

The dysfunction of the CSTC circuit has long been recognized as the neuroanatomical basis of OCD (Carmi et al., 2019; Tzirini et al., 2022). Abnormalities in the mPFC and ACC, key nodes of this circuit, constitute the target for dTMS (Carmi et al., 2019; Roth et al., 2021). In most protocols, high-frequency rTMS (typically 20 Hz) is most commonly used(Carmi et al., 2018, 2019; Roth et al., 2021). A comparative analysis of protocols (20 Hz, 1 Hz, and sham) showed that it was the high-frequency stimulation that significantly improved OCD symptoms compared to sham, leading to the termination of recruitment for the low-frequency group(Carmi et al., 2018). Stimulation is typically administered in a daily protocol for 6 weeks(Carmi et al., 2019). A crucial element of dTMS therapy for OCD is the individually tailored symptom provocation performed immediately before each dTMS session (Carmi et al., 2019; Roth et al., 2021; Tzirini et al., 2022). The purpose of this provocation is to activate the relevant neuronal circuit, making it more susceptible to changes induced by the stimulation(Roth et al., 2021; Tzirini et al., 2022).

The efficacy and safety of dTMS using the H7 coil were confirmed in a pilot study, and subsequently in a multicenter, sham-controlled study(Carmi et al., 2019; Roth et al., 2021; Tzirini et al., 2022). These results led to the approval by the US Food and Drug Administration (FDA) of dTMS with the H7 coil in August 2018 as an adjunct therapy for adult patients with OCD(Ozer et al., 2024; Silveira et al., 2022; Tzirini et al., 2022). Patients receiving active stimulation showed a significantly greater reduction in the YBOCS score (6.0 points) compared to sham (3.3 points)(Carmi et al., 2019). In the active group, the response rate was 38.1% after 6 weeks, compared to 11.1% in the sham group. This response was maintained at the one-month follow-up(Carmi et al., 2018; Tzirini et al., 2022). A naturalistic (post-marketing) study covering 219 patients showed that dTMS with the H7 coil has an even higher efficacy in real-world clinical settings than in rigorous controlled trials. The response rate reached 57.9% after 29 sessions, and 72.6% of patients achieved initial

response(Roth et al., 2021). The onset of clinical improvement with dTMS is relatively quick (after an average of 18–20 sessions), which is an advantage compared to pharmacotherapy and psychotherapy(Roth et al., 2021).

The mechanism of action for dTMS is hypothesized to involve interfering with or interrupting pathological activity within the CSTC circuits during a reconsolidation period, a state activated by symptom provocation (Roth et al., 2021). This interference subsequently strengthens compensatory activity in the brain(Roth et al., 2021). Beyond direct circuit modulation, electrophysiological changes have also been noted: clinical improvement in the HF-dTMS group correlated with an increase in Error Related Negativity (ERN) during a Stroop task(Carmi et al., 2018; Tzirini et al., 2022). The ERN is an event-related potential component attributed to ACC activity, strongly suggesting dTMS's ability to directly modify ACC function [3, 6]. Furthermore, stimulation impacts other neural networks, such as the Default Mode Network (DMN), leading to a decrease in anti-correlation within the Posterior Cingulate Cortex (PCC), a change potentially related to the reduction of obsessions(Carmi et al., 2018). dTMS utilizing the H7 coil is generally considered a safe and effective therapeutic intervention that can be considered for patients who have failed to receive sufficient benefit from previous pharmacological and psychological treatments(Carmi et al., 2019; Tzirini et al., 2022).

3.4. Safety and Side Effects

TMS, encompassing both repetitive rTMS and dTMS, is generally recognized as a safe and well-tolerated treatment modality for OCD(Conelea et al., 2024; Mikellides et al., 2021). TMS protocols have demonstrated safety and feasibility, often being associated with fewer adverse events compared to commonly prescribed medications(Conelea et al., 2024). The majority of side effects associated with TMS are mild and transient, resolving spontaneously without intervention. Headache is the most frequently reported adverse event, with incidence rates varying between protocols (e.g., 17.3% in a low-frequency rTMS group and 39% in a cTBS group)(Gautam et al., 2025). Other common, though usually minor, complaints include scalp discomfort or pain at the site of stimulation, as well as minor symptoms such as tingling and anxiety(Gautam et al., 2025). In rare instances, transient sensory phenomena, such as "flashes in the eye," lasting a few seconds, may occur following the initial sessions, but these typically regress spontaneously(Aydın et al., 2020). The most serious, though extremely rare, potential risk associated with any rTMS treatment is the induction of a seizure(Mikellides et al., 2021). The risk of a TMS-induced seizure is considered extremely low (reported as <1 in 60,000 sessions) in patients without specific risk factors(Mikellides et al., 2021). However, certain conditions, such as structural cerebral damage, sleep deprivation, or alcohol withdrawal, are known to potentially increase this minimal risk. Regarding stimulation frequency, approximately 51% of reported seizures occurred during high-frequency TMS protocols(Mikellides et al., 2021). Overall, strict adherence to established safety guidelines significantly mitigates the risk of serious adverse events, confirming TMS protocols as a tolerable and feasible treatment option for OCD patients (Conelea et al., 2024; Mikellides et al., 2021).

3.5. Practical and Clinical Considerations

The clinical implementation of TMS in OCD is controlled by specific patient selection criteria, and results are impacted by significant methodological heterogeneity across studies(Liu et al., 2021). Inclusion criteria are often rigorous, demanding a confirmed OCD diagnosis (DSM-5 or ICD-10) and a baseline symptom severity categorized as moderate to severe. However, patients with the most severe symptoms may be excluded due to concerns regarding protocol adherence and completion rates(Gautam et al., 2025; Guo et al., 2022; Liu et al., 2021). A substantial proportion of research focuses on individuals with treatment-resistant OCD, typically defined by insufficient response to at least two adequate sequences of SSRI treatment(Liu et al., 2021). For patients receiving concurrent pharmacotherapy, dose stability must be rigorously maintained for a predetermined period (e.g., 3 months) prior to and throughout the trial to accurately attribute clinical effects to the TMS intervention(Liu et al., 2021).

TMS, particularly dTMS targeting the ACC, is frequently utilized as an adjunctive treatment alongside stable medication regimens(Ozer et al., 2024). Evidence supports the efficacy of accelerated regimens (e.g., bi-daily dTMS), which may offer a path toward optimizing clinical response(Ozer et al., 2024). Furthermore, TMS may constitute a safer therapeutic alternative for patients with specific contraindications to SSRIs, such as those at risk for Reversible Cerebral Vasoconstriction Syndrome (RCVS)(Silveira et al., 2022). Considering the lack of standardization regarding optimal stimulation parameters (frequency, target site, coil type) in the existing literature, future research is imperative to refine protocols and establish effective strategies for maintenance therapy following the acute phase of treatment(Liu et al., 2021; Silveira et al., 2022).

4. Discussion

The primary goal of this review was to summarize the current evidence regarding the utility of TMS in the treatment of OCD, focusing on its neurobiological rationale, clinical efficacy across different targets, and practical considerations. The findings consistently support the role of TMS, particularly in patients with treatment-resistant OCD, as a valuable and generally well-tolerated adjunctive treatment option(Carmi et al., 2019; Conelea et al., 2024). The efficacy of TMS protocols fundamentally relies on the established neurobiological model of OCD, which posits a dysfunction within the CSTC circuits, with functional imaging studies repeatedly indicating hyperactivity in key nodes such as the ACC and OFC(Carmi et al., 2019; Ozer et al., 2024). This review confirms that TMS acts by modulating these altered networks: inhibitory rTMS (low-frequency) is employed to decrease the hyperactivity found in regions associated with compulsive behaviors and impaired inhibition, notably the SMA and right DLPFC(Chou et al., 2022; Conelea et al., 2024). Evidence, including a supporting meta-analysis, suggests that inhibitory SMA stimulation may be particularly effective(Rehn et al., 2018). Adequately, excitatory rTMS (high-frequency) protocols, especially dTMS, are used to modulate the deeper structures of the CSTC, primarily the medial prefrontal cortex (mPFC) and ACC(Carmi et al., 2019; Roth et al., 2021). The preSMA, characterized by overactivity even in healthy relatives, is strongly implicated in impaired inhibitory control, and its targeted modulation has shown effectiveness linked to individualized neurobiological correlates of network activity(Postma et al., 2025; Tzirini et al., 2022). Among the explored targets, the approach using dTMS with the H7 coil, which targets the mPFC-ACC, stands out due to its FDA approval as an adjunctive therapy for OCD(Ozer et al., 2024; Silveira et al., 2022). Clinical trials demonstrate significant superiority over sham, with a response rate of 38.1% in controlled settings and even higher rates (57.9%) observed in real-world clinical practice(Carmi et al., 2019; Roth et al., 2021). The mechanism of action for dTMS is hypothesized to involve interrupting pathological activity within the CSTC circuits during a reconsolidation period, a state activated by symptom provocation immediately preceding the stimulation (Roth et al., 2021). This is supported by electrophysiological evidence showing that clinical improvement correlates with an increase in ERN, an electrophysiological component attributed to ACC activity, suggesting that dTMS directly modifies ACC function(Carmi et al., 2018; Tzirini et al., 2022). In contrast, despite the pivotal role of the OFC in the CSTC loop, its utility as a TMS target remains limited and inconclusive, with trials often failing to show significant reductions in OCD symptoms, possibly due to technical challenges related to its anatomical location (Gautam et al., 2025; Guo et al., 2022; Liu et al., 2021).The clinical appeal of TMS is notably strengthened by its favorable safety profile. It is a well-tolerated intervention associated with fewer adverse events than commonly prescribed medications (Conelea et al., 2024). Side effects are typically mild and transient, primarily involving headache and scalp discomfort (Gautam et al., 2025). The most serious risk, seizure induction, is extremely rare (<1 in 60,000 sessions), though adherence to safety guidelines is mandatory to mitigate the minimal risk, which is slightly elevated in high-frequency protocols (Mikellides et al., 2021). However, practical implementation faces obstacles, including the methodological heterogeneity across studies, which complicates the standardization of optimal parameters(Liu et al., 2021). Furthermore, while trials frequently select patients with tr-OCD who maintain stable medication doses, TMS is also emerging as a crucial alternative for individuals with contraindications to SSRIs, such as the risk of RCVS (Liu et al., 2021; Silveira et al., 2022). In conclusion, TMS, particularly dTMS, represents a promising and safe adjunctive treatment for patients with refractory OCD. Future research must prioritize refining and standardizing protocols and leveraging neuroimaging to develop truly personalized TMS strategies that target individual functional connectivity patterns, while also establishing effective strategies for maintenance therapy (Liu et al., 2021; Silveira et al., 2022).

5. Conclusions

This review confirms that TMS is a safe, well-tolerated, and effective adjunctive treatment for patients with OCD, particularly those resistant to pharmacotherapy. dTMS targeting the mPFC and ACC is the most validated protocol, achieving FDA approval and demonstrating clinical superiority over sham treatment. Its mechanism is strongly supported by the need for symptom provocation to maximize neuroplastic change during the procedure.

The neurobiological rationale for TMS lies in modulating the hyperactive CSTC circuits. Inhibitory protocols, such as those targeting the SMA, offer a promising alternative by decreasing activity in structures linked to compulsive behavior.

Despite current efficacy, the field requires standardization of stimulation protocols and a shift toward personalized TMS strategies based on individual neuroimaging data. Furthermore, establishing effective long-term maintenance therapy protocols is essential to sustain clinical benefits.

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