The Effectiveness of Transcranial Magnetic Stimulation in Suicidality: An Updated Systematic Review

Manuele, S. J.[1]*, Cerins, A. [1]*, Jenkins, L. M.[1, 2], Thomas, E. H. X.[1], Sabetfakhri, N.[3], Cholakians, E.[1], Aaronson, A. L.[3,4†] & Chen, L.[1,5†]

*Joint First Authors
†Joint Senior Authors

[1] Department of Psychiatry, School of Translational Medicine, Monash University, Melbourne, Victoria, Australia
[2] Department of Psychiatry and Behavioral Sciences, Stephen M. Stahl Center for Psychiatric Neuroscience, Feinberg School of Medicine, Northwestern University, Chicago, IL, USA
[3] Department of Psychiatry, University of Illinois, Chicago, Chicago, Illinois, USA
[4] Mental Health Service Line, Edward J. Hines VA Hospital, Department of Veterans Affairs, Hines, Illinois USA
[5] Alfred Mental and Additional Health, Alfred Health, Melbourne, Victoria, Australia

Corresponding Author: Dr. Leo Chen; leo.chen@monash.edu

Declarations and Disclosures

The Authors declare they have no conflicts of interest to disclose.

Declaration of generative AI and AI-assisted technologies in the writing process.

During the preparation of this work the authors used Elicit (Oakland, CA) to perform an initial data extraction from the included studies to populate author-defined table columns. After this assisted extraction, the authors reviewed and edited all the extracted content based on each included study. The authors take full responsibility for the content of the published article.

Funding

Research reported in this publication was supported by the National Institute of Mental Health of the National Institutes of Health under Award Number R01MH132920 (**LMJ**). The content is solely the responsibility of the authors and does not necessarily represent the official views of the National Institutes of Health. LC is supported by philanthropic funding from the Blue Sky Foundation, the Natwes Foundation and project funding from the Australian Government Department of Health and Aged Care. ALA is supported by the Department of Veterans Affairs Office of Research and Development, Rehabilitation Research and Development CDA2 award (IK2RX004298).

Abstract

Suicidal thoughts and behaviors (STB) have a substantial global burden, with over 14 million individuals attempting suicide annually**.** Existing biological therapies do not adequately reduce STB risk. Repetitive transcranial magnetic stimulation (rTMS) is an approved, non-invasive and low-risk treatment for several psychiatric disorders. Meta-analyses investigating TMS' effects on STB indicate therapeutic promise. Given the proliferation of TMS studies investigating its effect on STB, a repeat review of the literature is warranted. **Methods:** A PRISMA-guided systematic review was conducted to evaluate the efficacy of rTMS in reducing STB. Studies assessing STB outcomes following rTMS to treat psychiatric disorders, either as monotherapy or adjunctive treatment, were included. Forty-five studies were identified (*N*=3515). **Results:** Studies generally applied rTMS to treat primary psychiatric disorders, particularly depression, with change in suicidality evaluated as a secondary outcome. rTMS protocols differed across studies. Most studies targeted the left dorsolateral prefrontal cortex (dlPFC), although significant improvements to STB were also reported with rTMS targeting the visual cortex, right dlPFC and the bilateral PFC. High frequency rTMS and intermittent theta burst stimulation (iTBS) protocols were superior in reducing STB compared to other stimulation protocols, with studies reporting 40-100% treatment response rates. Adverse events (AEs) were mostly mild and transient. **Conclusion:** rTMS appears to be a safe and effective treatment option for STB, with significant reductions observed, particularly when rTMS or iTBS is applied to the dlPFC. Mechanistically informed randomized controlled trials specifically designed to evaluate rTMS' treatment effects on STB are needed to validate this promising treatment approach.

Introduction

Globally, more than 14.5 million people attempt suicide each year, with over 725,000 deaths resulting from suicide (*World Health Organization*, 2024). Suicidal thoughts and behaviors (STB) can occur in the context of nearly any psychiatric diagnosis, but can also occur in individuals without a psychiatric disorder (Caudle et al., 2024). STB have been linked to a range of risk factors, including stress, maladaptive emotion and pain regulation, reward seeking, and cognitive and inhibitory control deficits that often occur from a range of mental and physical health problems, as well as environmental stressors (Abdollahpour Ranjbar et al., 2024; Barredo et al., 2021).

There are biological, psychological and behavioral strategies to manage STB though the efficacy of each strategy is limited. Pharmacotherapy (e.g., antidepressants, mood stabilisers, antipsychotic medications and ketamine compounds) is often used (Zisook et al., 2023). However, while Ketamine studies have shown promise in rapidly alleviating STB, side effects varied (e.g., sedation, depersonalization, agitation, nausea) and benefits were reported to last up to two weeks (Abbar et al., 2022; Bruton et al., 2025; Wilkinson et al., 2018). The short window of symptom alleviation may result in post-ketamine treatment STB spikes (Ingrosso et al., 2025; Lascelles et al., 2021). Further, A recent meta-analysis examining the effects of the ketamine enantiomer, esketamine, on STB reported limited efficacy. Electroconvulsive Therapy (ECT), an evidence-based and relatively rapid-acting treatment for several psychiatric conditions, , may be used as an STB treatment (Salik & Marwaha, 2025). However, stigma and concerns regarding cognitive and memory side effects may limit its acceptance as a treatment option (Argyelan et al., 2021; Porter et al., 2020). Further, ECT requires the administration of general anaesthesia, thus exposing those receiving ECT to its inherent risks (Salik

& Marwaha, 2025). Implications to blood pressure, heart rate and intracranial pressure may contraindicate ECT for those with central nervous system, respiratory and cardiovascular issues (Salik & Marwaha, 2025). Evidence for the effectiveness of manualized psychological therapies in treating STB, namely cognitive-behavioral therapy and dialectical behavior therapy, appears mixed (Sufrate-Sorzano et al., 2023).

Overall, meta-analyses suggest existing STB treatments have varying efficacy. One study examined 29 placebo-controlled trials, ultimately concluding there was inadequate evidence to support antidepressants, as a treatment to prevent STB (Braun et al., 2016). Antidepressant interventions for STB are not immediate acting, creating vulnerability for those with active STB (Del Matto et al., 2020). Pharmacotherapy often requires trialling of numerous medications to experience symptom reduction, while remission is often dosage dependent. Ongoing continuation or maintenance, as well as strict adherence to guidelines for ECT, ketamine and pharmacotherapy are often necessary but underutilized for sustained benefit (Jørgensen et al., 2024). The limitations of current interventions highlight a critical gap in effective, tolerable treatments for suicidality – one that emerging neuromodulation techniques may begin to address. Thus, there is a critical unmet need for innovative treatments that are both effective and tolerable for reducing suicidality.

Repetitive transcranial magnetic stimulation (rTMS), a non-invasive brain stimulation technique, is approved by the Food and Drug Administration (U.S. FDA) as an evidence-based treatment for several neuropsychiatric conditions, such as major depression (Cohen et al., 2022; Mutz et al., 2018). These studies target the dorsolateral prefrontal cortex (dlPFC) due to its implication in mood symptoms.

Emerging literature report the effects of stimulation applied to target the motor, anterior cingulate and orbitofrontal cortices as treatment sites for other psychiatric conditions, many of which may have heightened STB risk (Han et al., 2023; Lusicic et al., 2018).

There is a pressing need for novel treatment strategies that can reduce STB. An expanding body of clinical trial data suggests that rTMS may effectively reduce STB. The most recent review of the literature reporting on rTMS's efficacy in treating STB occurring transdiagnostically was published in 2022 (G.-W. Chen et al., 2022). A substantial number of studies of this promising approach to alleviating suicidal ideation have been published since (Aaronson et al., 2024; Adu et al., 2023; Hickson et al., 2024; Huang et al., 2025; Kong et al., 2023; Li et al., 2024; Pan et al., 2023; Sun et al., 2024; Terpstra et al., 2023; Thai et al., 2024; Wilkinson et al., 2023; Zhan et al., 2024; Zhao et al., 2024; Zhao et al., 2023). Given the volume of new data available and the urgent need for novel intervention strategies, this systematic review provides an updated insight into the current literature investigating the efficacy of rTMS in individuals experiencing STB. Further, this review aims to address the efficacy of various rTMS modalities and protocols on STB symptoms including suicidal ideation, attempts, and behaviors.

Methods

A systematic review of the existing literature regarding the efficacy of TMS in individuals with STB was conducted, utilizing the Preferred Reporting Items for Systematic Reviews and Meta-Analyses (PRISMA) guidelines (Page, McKenzie, et al., 2021; Page, Moher, et al., 2021).

Search Strategy

Using PubMed and Web of Science databases, a literature search was conducted. Search terms included suicid*, transcranial magnetic stimulation, TMS.

To ensure rigorous assessment of the existing literature, publications were not limited by date. The final study search was completed on February 12, 2025. Studies which were published until February 2025 were included. See Figure 1 for PRISMA flow diagram.

Inclusion Criteria and Study Selection

Intervention: Studies which assessed TMS independently or as an adjunct treatment for STB were included. This review included studies regardless of TMS site, type (i.e. Repetitive [rTMS]; Deep [dTMS], Intermittent Theta Burst [iTBS], Accelerated iTBS, Low Frequency rTMS [LFR rTMS] or Continuous Theta Burst [cTBS]), trial duration, frequency (Hz) or number of pulses delivered.

Outcome Measures: Studies which assessed STB as a primary or secondary outcome were included if measures of STB were collected at multiple timepoints. In addition, studies which measured self- or clinician-rated, or in the instance of youth studies, parent-rated STB, were included.

Population: Studies which included participants who reported STB. Studies were not excluded if they had participants with comorbid psychiatric conditions. No exclusion criteria were specified for age of participants, or concurrent or past treatment or intervention methods.

Comparison/Placebo/Control Group: Studies considered for this review were not required to have recruited a comparison or control group or have administered sham TMS.

Study Type: Studies which used observational or interventional designs, such as randomized controlled trials, clinical trials, cohort studies, open-label studies, pilot studies and case-control studies, were included. Individual case reports, reviews and summary publications were excluded. Studies were also required to be published and/or available in English. Gray literature and published dissertations were excluded.

Data Screening

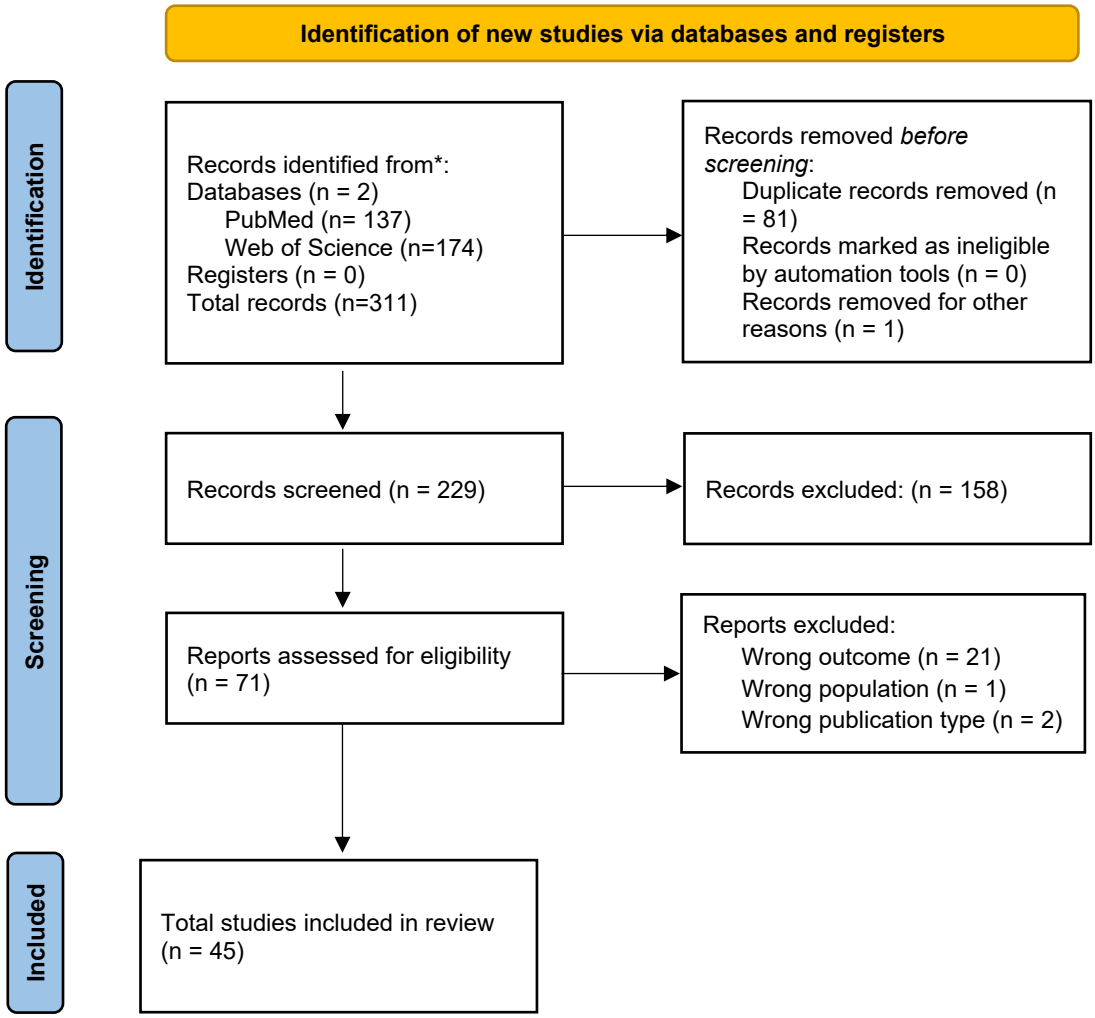
Rayyan software (https://www.rayyan.ai/; Ouzzani et al., 2016) was utilized to screen the identified literature. After duplicate screening and exclusion by Rayyan, study screening was conducted by AC and SJM, independently. Full text retrieval was conducted for manuscripts which met inclusion criteria, and full text screening was completed by SJM. Disagreements were resolved by AC and SJM. Studies excluded at full text screening stage and exclusion reason are listed in Figure 1.

Data Extraction

Information from included studies was extracted, including study design, intervention details such as protocol, frequency, location and number of TMS treatments, use of neuronavigation for treatment, adverse events or side effects of treatment, demographic information, baseline and follow up symptomatology, and pre-existing comorbidities. See Supplementary Materials for data extraction table.

Figure 1.

PRISMA Flow Diagram



Results

A database search yielded 311 studies for consideration, of which 81 were identified as duplicates. The remaining 229 articles were title and abstract screened. We excluded 158 articles at the title and abstract screen phase, resulting in 71 full texts screened. The final number of studies included in the review was 45, with most studies excluded at the full text screening stage due to incorrect outcome measured (namely depressive symptoms which encompassed STB but did not address change in STB independently). A PRISMA flow chart is presented in Figure 1. The 45 included studies encompassed a total sample size of 3,515 participants, ranging in age from 13 to 80 years. Most studies however, included adult samples, with mean ages between 40 to 55. Additionally, of the 44 studies (*n*=3483) that provided sex distribution of the samples, 67.4% of participants were female.

The studies included in this review implemented various TMS modalities, including repetitive TMS (rTMS), deep TMS (dTMS), intermittent theta burst stimulation (iTBS), continuous theta burst stimulation (cTBS), and accelerated protocols for iTBS and cTBS. Participants enrolled in these studies had existing diagnoses of TRD (*n*=22), Depression or MDD (*n*=20), bipolar disorder (BD) (*n*=2), BPD (*n*=1), PTSD (*n*=3), and/or Traumatic Brain Injury (TBI) (*n*=2). While most studies treated the left dlPFC, other targets included the visual cortex (VC), right dlPFC, dorsomedial prefrontal cortex (dmPFC), and the bilateral dlPFC. Additionally, the anterior cingulate cortex (ACC) was targeted with dTMS. STB measures varied substantially across studies, with some administering STB specific questionnaires (e.g., Columbia Suicidal Severity Rating Scale [C-SSRS]; Beck Suicidality Index [BSI]), and others extracting suicide-related items from broader questionnaires (e.g., Hamilton Depression Rating Scale Item 3, [HAMD]; Montgomery-Asberg Depression

Rating Scale Item 10 [MADRS]). Finally, protocols for identifying TMS treatment site varied, with studies using neuronavigation (*n*=17), participant anatomical scalp measures (*n*=15), BeamF3 (*n*=2), and some unspecified, while H1 coils were implemented for dTMS protocols (*n*=2). Scalp measured varied in distance from reference region, and reference region. See Table 1 for study details.

Table 1. Study details

Author	Design	Demographics	Diagnoses	Protocol	Measures & Timepoints	Adverse Events (n/%)	Key Findings
Aaronson et al., 2024	Open-label Pilot	N= 31 Mean age: 42.2 (SD=14.3), 58% female	BD ft Depressive Episode	TMS: scalp measured rTMS Location: L dlPFC Frequency: 10Hz Pulses: 3000 per session Sessions: 35 Intensity: 120% MT	C-SSRS 1. Screening 2. Baseline 3. Post intervention	Agitation Worsened sleep (6.5%)	C-SSRS score decreased from 3.74 to 0.75 Response rates: 87.1% Remission rates: 74.2%
Abdelnaim et. al., 2020	Retrospective	N=332 Mean age: 47.3 (SD=12.3), Range: 20-79 years, 54.2% female	Depressive Disorders	TMS: rTMS, dTMS, iTBS, cTBS Frequency, Pulses & Location: For 79% of retrospective sample: 20 Hz, 2000 pulses, (L PFC) Remaining 21% of sample: 10 Hz, 2000 pulses, (L PFC) 10 Hz. 1000 pulses, (L PFC) 20 Hz, 2000 pulses, (R PFC) 1 Hz, 1000 pulses, (R PFC) 10 Hz, 2000 pulses, (ACC) 20 Hz, L PFC then 1 Hz R PFC, 2000 pulses iTBS L PFC then cTBS R PFC 2,400 pulses Sessions: 6 - 50	HAMD Item 3 1. Baseline 2. Post intervention	Not reported for this study	47% showed improvement, 41.3% no change, 11.7% worsened STB, p<.001. One rTMS participant completed suicide during treatment.
Adu et al., 2023	RCT	N=78 Range: 18-65 (7.7% <25, 42.3% 26-40, 50% >40) 64.1% female	TRD	TMS: scalp measured rTMS Location: B dlPFC Frequency: 1Hz right, 10Hz left Pulses: 4200 per session Sessions: 30 Intensity: 120% MT	C-SSRS 1. Baseline 2. Post intervention	Transient headaches Dizziness Scalp discomfort	41% reduction in CSSRS scores from baseline to 6 weeks. No significant difference between the treatment groups (rTMS vs. rTMS plus iCBT) regarding changes in suicidality.
Baeken et al., 2017	RCT	N=44 Mean age: 41 (SD=12), 72.7% female	TRD	TMS: Neuronavigaged a-iTBS Location: L dlPFC Pulses: 1620 per session Sessions: 20 Intensity: 110% MT	HAMD, SSI, BHS 1. Baseline 2. Treatment one 3. Treatment two 4. Treatment three	Not reported for this study	Significant reduction in SSI scores
Baeken et al., 2019	RCT	N=45 Mean age: 44 (SD=19), 72.7% female	TRD	TMS: Neuronavigated a-iTBS Location: L dlPFC Pulses:1620 per session Sessions: 20 Intensity: 110% MT	BSI, BDI 1. Baseline 2. Treatment two 3. Treatment three 4. Follow up	Not reported for this study	Decrease in BSI scores broadly, with sham arm showing a significant decrease (p=.03) compared to active arm (p=.06)
Barredo et al., 2021	Open-label trial	N=25 Mean age: 52.4 (SD=10), 48% female	PTSD & MDD	TMS: BeamF3 rTMS Location: B PFC Frequency: 5Hz Pulses: 3000-4000 total Sessions:13-40 Intensity: 120% MT	ISD-SR, DSM-V PTSD Module 1. Baseline 2. Post intervention	Not reported for this study	65% of participants experienced a reduction

Berlim et al., 2014	Open-label pilot	N=17 Mean age: 47.12 (SD=13.26), Range: 25-68, 76.5% female	TRD	TMS: scalp measured dTMS Location: L dlPFC Frequency: 20Hz Pulses: 3000 per session Sessions: 20 Intensity: 120% MT	BSI 1. Baseline 2. Post intervention	Scalp discomfort (11.76%)	Response rates were 70.6%, while remission rates were 41.2%. SSI scores reduced from 10.88 to 8.12
Bloch et al., 2008	Open-label Pilot	N=9 (Adolescent Sample) Mean age: 17.3, Range=16-18, 77.8% female	TRD	TMS: scalp measured rTMS Location: L dlPFC Frequency: 10Hz Pulses: 400 per session Sessions: 14 Intensity: 80% MT	BSI 1. Baseline 2. Day 7 3. Day 10 4. Week 3 5. One month	Mild headache (5) Hypomanic episode (1)	No significant changes in suicidality were identified
Bozzay et al., 2020	Retrospective	N=43 (Veteran Sample) Mean age: 55 (SD=12.5), Range: 27-73. 11% female	TRD	TMS: BeamF3 rTMS Location: L dlPFC Frequency & Pulses: 5Hz, 3000-4000 pulses 5Hz, 3000-4000 pulses & 10Hz, 4000 pulses, per session Sessions: 15-40 Intensity: 120% MT	PHQ-9, IDS-SR 1. Baseline 2. Post intervention	Not reported for this study	Significant decreases in suicidal ideation. Remission rates for suicidal ideation were 58% on the PHQ-9 and 62% on the IDSSR
Caldeon-Moctezuma et al., 2022	RCT	N=14 Mean age: 26.07 (SD=7.3), 64.3% female	BPD	TMS: rTMS Location: dmPFC Frequency: 5Hz Pulses:1500 per session Sessions: 15 Intensity: 100% MT	BIS, HAMD, BSL-S, CGI-BPD, HAMA 1. Week one 2. Week two 3. Week three	Headache (active [1] and sham [1]), discomfort (1), dizziness (1)	There were no significant differences between groups or within groups in change to suicidality symptoms
Chen et al., 2022	RCT	N=105 Mean age: 47.09 (SD=13.49), 67.6% female	TRD	TMS: iTBS & rTMS Location: L dlPFC Frequency: 50Hz (iTBS), 10Hz (rTMS) Pulses: 1800 per session Sessions: 10 Intensity: 100% MT (iTBS), 80% MT (rTMS)	HAMD Item 3 1. Baseline 2. Day seven 3. Day fourteen 4. Day twenty-eight 5. Three months	Not reported for this study	iTBS had a similar antisuicidal effect to ketamine at Day 14 and a stronger effect than rTMS at Day 14 and month 3.
Croarkin et al., 2018	Open-label pilot	N=19 (Adolescent Sample) Mean age: 16 (SD=1.29), Range: 13-19, 68.42% female	TRD	TMS: Neuronavigated rTMS Location: L dlPFC Frequency: 10Hz Pulses:3000 per session Sessions:30 Intensity: 120% MT	CDRS-R, C-SSRS 1. Baseline 2. Week two 3. Week four 4. Week six	Not reported for this study * 1 participant withdrew due to increased SI	83.33% showed no suicidal ideation post-treatment on CDRS-R & 70.59% on C-SSRS. Response rates: 55.56% showed improvement on CDRS-R Item 13 & 58.82% on C-SSRS.
Dai et al., 2022	RCT	N=89 Mean age: 43.2 (SD=9.39), 67.4% female	Depression	TMS: scalp measured rTMS Location: L dlPFC Frequency: 10Hz Pulses: 8000 per session Sessions: 20 Intensity: 100% MT	SIOSS, HAMD 1. Baseline 2. Week two 3. Week four	Discomfort (3) Mild headache (2), Nausea (1)	Significant reduction in SIOSS scores. Response rates: Active rTMS had a response rate of 97.5%, significantly higher than sham of 79.6%

Dai et al., 2020	RCT	N=103 Mean age: 68.2 (SD=9.37), 65.1% female	Depression	TMS: rTMS Location: L PFL Frequency: 10Hz Pulses: 800 per session Sessions: 20 Intensity: 100% MT	SIOSS, HAMD 1. Baseline 2. Week two 3. Week four	Headache Nausea Mouth dryness (control [3]) Constipation (control [3]) Dizziness (active [5]) Chest tightness (active [5])	Significant reduction in SIOSS, p<.050 at 2 weeks, p<.010 at 4 weeks. After 2 weeks, 52.1% in rTMS vs. 32.7% in sham; after 4 weeks, 93.8% in rTMS vs. 83.6% in sham.
Davila et al., 2019	Retrospective	N=247 Mean age: 42.9 (SD=13.9), Range: 18-78, 60.3% female	MDD	TMS: rTMS Location: L dlPFC Frequency: 10Hz Sessions: up to 30	PHQ-9 Not reported for suicidality measure	Discomfort	Remission rate of 72%. 80% of patients with a history of SA achieved remission vs 67% without SA history (p=0.030)
Desmyter et al., 2016	RCT	N=50 Mean age: 41.9 (SD=11.77), 70% female	TRD	TMS: Neuronavigated iTBS Location: L dlPFC Frequency:50Hz Pulses: 1620 per session Sessions:20 Intensity: 110% MT	BSI, HAMD 1. Baseline 2. Week one 3. Week two 4. One Month 5. Six months	Discomfort Headaches	Significant decrease in BSI scores (p<.010) between T1 and T2. The decrease in suicide risk lasted up to 1 month after baseline, even in depression non-responders.
George et al., 2014	RCT	N=41 Mean age: 42.5 (SD=15.7), 15% female	Depressive Episode (I or II)	TMS: scalp measured rTMS Location: L dlPFC Frequency: 10Hz Pulses: 3000 per session Sessions: 9 Intensity: 120% MT	BSI, VAS, HAMD, MADRS, CGI-S 1. Baseline 2. Day one 3. Day two 4. Day three 5. Discharge 6. Three months 7. Six months	Second degree burn (1) Headache Eye pain/twitching	Mean change from baseline -15.6 for rTMS and -15.3 for sham, both groups showed a decline in SSI scores over 3 days. More rapid improvement on the first day with active rTMS (p= .120). No significant difference in treatment
Hadley et al., 2011	Retrospective	N=19 Mean age: 48 (SD=16), Range: 17-80, 57.9% female	TRD	TMS: scalp measured rTMS Location: L dlPFC Frequency: 10Hz Pulses: 6800 per session Sessions: 3-116 Intensity: 120% MT	BDI, BSI, ATHF, Q-LES-Q 1. Baseline 2. Week one 3. Unspecified	Discomfort/Pain (2) * These participants withdrew due to pain intolerance	67% of patients experienced decreased symptoms (p<.0001) per session. Mean SSI score decreased from 10.8 at baseline to 7.1 after week one. Improvement in suicidal thinking between 0% to 77%.
Hickson et al., 2023	RCT	N=99 Mean age: 48.14 (SD=12.94), 34.34% female	TRD	TMS: H1 Coil dTMS Location: L dlPFC Frequency: 18Hz Pulses:1980 per session Sessions: 30 Intensity: 120% MT	PHQ-9, DSM-V PTSD module, BSI 1. Baseline 2. Post intervention 3. Three months 4. Six months	Seizure (1) due to incorrectly placed coil (motor strip)	Significant reduction to symptoms post-intervention, 3-month, and 6-month follow-up, with 54.02% reduction to symptoms at 6 month follow up.
Hines et al., 2021	RCT	N=120 Mean age: 28.3 (SD=6.9), 28% female	PTSD (20%) TBI (8%) Depression ft SI (66%)	TMS: neuronavigated rTMS Location: L dlPFC Frequency: 10Hz Pulses: 4000-5000 per session Sessions: 9 Intensity: 120% MT	BSI, C-SSRS 1. Baseline 2. Day one 3. Day two 4. Day three 5. One month	Discomfort/Pain Flu-like respiratory symptoms Gastroenteritis-like symptoms	Active TMS led to a statistically significant decline in SI compared to sham (p=.040). Mean final SSI-C scores were below 3 for active TMS, indicating lower suicide risk.

					6. Three months 7. Six months	*30.5% of active and 11.5% discontinued due to adverse events	
Huang et al., 2025	RCT	N=110 MDD (n=70), Mean age: 21.70 (SD=5.4), 55.7% female control group (n=40), Mean age: 20.40 (SD=1.5), 40% female	MDD ft. anhedonia	TMS: neuronavigated rTMS & iTBS Location: L dlPFC Frequency, Pulses & Intensity: 10Hz, 3000, 100% MT (rTMS), 50Hz, 600, 80% MT (iTBS) per session Sessions:15	BSI-CV 1. Baseline 2. Post intervention	Not reported for this study	Significant improvement in suicidal ideation symptoms, rTMS <.001, iTBS:p=.002.
Keshtkar et al., 2011	RCT	N=73 rTMS group (n=33), Mean age: 34 (SD=9.9), 60% female ECT group (n=40), Mean age: 35.6 (SD=8.1), 80% female	TRD	TMS: scalp measured rTMS Location: L dlPFC Pulses: 4080 per session Sessions: 10 Intensity: 90% MT	BDI, HAMD 1. Baseline 2. Post intervention	Headache (1)	Significant reduction to suicidality scores, although ECT was more effective than rTMS
Kong et al., 2024	RCT	N=75 Mean age: 30 (SD=13), 78% female	MDD	TMS: neuronavigated iTBS Location: L dlPFC, VC Frequency: 50Hz, repeated at 5Hz Pulses: 600 per session Sessions: 28 Intensity: 120% MT	BSI-CV, HAMD Item 3, MADRS Item 10 1. Baseline 2. Day one 3. Day 3 4. Day 5 5. Day 7 6. Day 10 7. Day 14 8. One month 9. Three months	Headache (>50%) Scalp discomfort (>50%) Dizziness (20%) Abnormal facial sensation (20%) Eye/Nose/Jaw/Teeth discomfort Blurred vision Photopsia	Suicidal ideation scores decreased both groups. Response rates: 89% in VC group and 78% in dlPFC group at treatment end. Remission rates: 71% in the VC group and 63% in the dlPFC group at treatment end (not statistically significant).
Li et al., 2024	Open-label pilot	N=32 Mean age: 27.66 (20.38)	MDD ft SI	TMS: neuronavigated iTBS Location: L dlPFC Pulses: 10800 per session Sessions:10 Intensity: 90% MT	BSI-CV, HAMD Item 3, MADRS Item 10 1. Baseline 2. Post intervention 3. Two weeks 4. Four weeks	Headache (56.25%) Scalp numbness (26.47%) Nausea (11.76%) Jaw twitching (8.82%) Teeth discomfort (5.88%) Tinnitus (2.94%) Palpitations (2.94%) Weeping (11.76%)	Significant reductions to scores for HAMD-17 item 3 and MADRS item 10, with 65.23% reduction in BSI score after treatment, p<.001.
Mehta et al., 2022	RCT	N=301 (Subsample from the **THREE-D trial)** non-remission group: Mean age: 41.6 (11.6), 57.4% female. Remission group: Mean age: 44.2 (SD=10.9), 63.1% female.	TRD	TMS: neuronavigated rTMS & iTBS Location: L dlPFC Frequency & Pulses: 10Hz, 3000 (rTMS), 50Hz repeated at 5Hz, 600 (iTBS) Sessions: 20-30 Intensity: 120% MT	HAMD Item 3, IDS-30 Item 18, QIDS-SR16 Item 12 1. Baseline 2. Every fifth treatment 3. Post intervention	Not reported for this study	Remitted in 43.7% for rTMS group, and 49.1% in iTBS groups with, with average remission time 3.2 weeks for rTMS and 3.1 weeks for iTBS No significant group difference
Ozcan et al., 2020	Open-label case-series	N=27 85.2% aged between 35-55. 70.3% female	TRD	TMS: scalp measured rTMS Location: L dlPFC Frequency: 20Hz Pulses: 1000	C-SSRS, BSI, BHS 1. Baseline 2. Post intervention	Not reported for this study	Significant decrease in STB p<.001, on both C-SSRS and SIS scales.

				Sessions:20-30 Intensity: 100% MT			
Pan et al., 2018	RCT Case Series	N=3 (Adolescent sample) Range: 15-17 66.7% female	MDD	TMS: neuronavigated rTMS Location: L dlPFC Frequency: 10Hz Pulses: 6000 per session Sessions:7 Intensity: 100% MT	BDI, HAMD Item 3, MADRS 1. Baseline 2. Day three 3. Day seven	Not reported for this study	40.01-100% improvement on BSI scores
Pan et al., 2022	RCT	N=59 Active arm: Mean age: 18 (SD=3.96), 67.7% female Sham arm: Mean age: 20.60 (SD=5.77), 71.4% female	MDD	TMS: neuronavigated rTMS Location: L dlPFC Frequency: 10Hz Pulses: 6000 per session Sessions: 7 Intensity:100% MT	BSI-CV 1. Baseline 2. Day three 3. Day seven	Hypomania (66.7%) Fatigue/Drowsiness	Significant reduction in BSI scores, p<.001, with active arm showing greater reduction than sham
Petrosino et al., 2019	RCT	N=46 (Veteran sample) Mean age: 51 (SD=12.3), 84.4% female	PTSD	TMS: iTBS Location: R dlPFC Frequency: 50Hz Sessions: 10-20	DSM-V PTSD Module, IDS-SR, QIDS 1. Retrospective	Not reported for this study	Clinically meaningful superiority of 4-week active iTBS group. 2-week group more likely to relapse and did so sooner.
Rao et al., 2019	RCT	N=30 Active arm (n=13) Mean age: 39.8 (SD=14.2) 61.5% female Sham arm (n=17) Mean age: 40.2 (SD=14.6) 35.3% female	MDD post TBI	TMS: rTMS Location: R dlPFC Frequency: 1Hz Pulses: 1200 per session Sessions: 20 Intensity: 110% MT	BSI 1. Baseline 2. Post intervention	Headaches Worsened mood Dizziness Scalp Discomfort Insomnia Face tightness/twitching Tooth pain	There were no statistically significant differences in response or remission rates between the rTMS and sham groups.
Sun et al., 2024	Open-label trial	N=123 (Adolescent sample) Navigated TMS (n=33), Mean age: 16.52 (SD=2.76), 75.8% female 5cm positioning TMS (n=41), Mean age: 16.41 (SD=2.53), 78.1% female Pharmacotherapy arm (n=49), Mean age: 16.14 (SD=1.35), 78% female, Range: 13-18	MDD	TMS: neuronavigated rTMS Location: L dlPFC Frequency: 10Hz Pulses: 2400 per session Sessions: 10 Intensity: 90% MT	BSI-CV 1. Baseline 2. Week one 3. Week two	Dizziness (2.4%)	Significant reduction in SI intensity, p<.001, with sMRI navigated group showing a greater reduction in symptoms
Tang et al., 2021	Open-label pilot	N=30 MDD group (n=15) Mean age: 25.8, 86.7% female Healthy controls (n=15) Mean age: 32.3, 80% female	MDD ft SI	TMS: neuronavigated iTBS Location: L dlPFC Pulses: 1800 per session Sessions: 10 Intensity: 90% MT	BSI-CV, HAMD Item 3, MADRS Item 10 1. Baseline 2. Post intervention 3. Day fifteen 4. One month	Scalp numbness and pain (2)	Significant reduction in BSI-CV, HAMD, and MADRS scores (p<.001). Response rates: 86.67% after 5 days, 80% after 15 days, and 93.33% after 30 days.
Terpstra et al., 2022	Open-label trial	N=55 Mean age: 42.4 (SD=15.5), Range: 19-78, 71% female	TRD	TMS: neuronavigated LFR rTMS Location: R dlPFC Frequency: 1Hz Pulses:1800 per session Sessions:20 Intensity: 120% MT	CHRT, MADRS 1. Baseline 2. Week two 3. Week four 4. Week five	Not reported for this study	Significant decrease in CHRT Total, Propensity, and Risk scores from baseline to week 17, p<.001.

					5. Week seventeen		
Thai et al., 2024	Open-label Pilot	N=14 (Adolescent sample) Mean age: 16.4 (SD=1.42) 60% female	TRD	TMS: H1 coil dTMS Location: L dlPFC Frequency: 10Hz Pulses:1980 per session Sessions: 30 Intensity: 80%-120% MT	C-SSRS 1. Baseline 2. Post intervention 3. Monthly follow up for six months	Convulsive syncope Headaches (93.3%) Light-headedness Dizziness Anxiety	Significant decrease in suicidality, p<.001, sustained over 6 months post intervention. Baseline and post-intervention suicidality scores: Mean change of 2.93 (SD = 3.71)
Wall et al., 2011	Open-label Pilot	N=8 (Adolescent sample) Mean age: 16.5, Range: 14.6-17.8, 87.5% female	TRD	TMS: scalp measured rTMS Location: L dlPFC Frequency: 10Hz Pulses: 3000 per session Sessions: 30 Intensity: 120% MT	C-SSRS 1. Baseline 2. Post Intervention 3. Six months	Scalp discomfort (37.5%) * 1 participant withdrew due to scalp discomfort	Suicidal ideation improved in 3 adolescents during treatment. At treatment completion, only 1 adolescent had passive suicidal ideation persisting at follow-up.
Wang et al., 2022	Open-label Pilot	N=31 Mean age: 46.03 (SD=7.10), Range: 18-60, 41.94% female	TRD ft SI	TMS: scalp measured rTMS Location: L dlPFC Frequency: 15Hz Pulses: 750000 total Sessions: 25 Intensity: 110% MT	C-SSRS 1. Baseline 2. Day five 3. Week four	Dizziness (12.9%) Scalp discomfort (22.58%)	Response rates: 100% at day 5, 83.87% at week 4. Remission rates: 87.09% at day 5, 77.42% at week 4.
Wang et al., 2024	Open-label Pilot	N=119 Mean age: 46.2 (SD=10.78), Range: 18-67, 57.14% female	TRD	TMS: scalp measured a-rTMS Location: L dlPFC Frequency: 15Hz Pulses: 75000 total Sessions:25 Intensity: 110% MT	C-SSRS 1. Baseline 2. Four weeks post-intervention	Not reported for this study	Significant improvement in C-SSRS scores from baseline to T1 and T2 (p<.010). Response rates: 57.98% at T1 and 48.74% at T2 across general symptomatology.
Weissman et al., 2018	RCT	N=156 Unilateral TMS (n=56), Mean age: 47.4 (SD=13.8), 71.4% female Bilateral TMS (n=52), Mean age: 49.4 (SD=13.4), 53.8% female Sham arm (n=48), Mean age: 47.1 (SD=12.2), 60.4% female	TRD	TMS: scalp measured rTMS & B rTMS Frequency: 10Hz, 1450-2100, L dlPFC, 1Hz, 465-600 (R dlPFC) then 10Hz, 750-1500 (L dlPFC), per session Sessions: 15 Intensity: 100%-120% MT	HAMD Item 3 1. Baseline 2. Week three or week 6* *participant dependent	Not reported for this study	SI resolved in 40.4% of B rTMS, significantly higher than 18.8% in sham. Response rates: B rTMS significant response vs. sham (*p*=.020), L rTMS did not show significant response (*p*=.330). Remission rate: 25.8% B rTMS
Wilkening et al., 2022	RCT	N=81 Mean age: 35.65 (SD=13.03), 41.98% female	MDD	TMS: a-iTBS Location: L dlPFC Frequency: 5Hz (volleys), 50Hz (individual burst) Pulses: 36000 total Sessions: 40 Intensity: 110% MT	MADRS Item 10, HAMD Item 3, BDI-II Item 9 1. Baseline 2. Week one 3. Week two 4. Week three 5. Week four 6. Post intervention	Headache (52.47%) Scalp discomfort (56.18%) Scalp irritation (20.99%) Neck pain (30.25%)	Significant reduction in suicidality with a 34.61% average decrease in suicide scores. 62% of participants showed a decrease in suicidality scores; 21% showed no change; 17% showed an increase.

Yesavage et al., 2018	RCT	N=164 Mean age: 55.2 (SD=12.4), 19.5% female	MDD	TMS: rTMS Location: L dlPFC Frequency: 10Hz Pulses: 4000 per session Sessions:20-30 Intensity: 120% MT	C-SSRS 1. Baseline 2. Post intervention 3. Week 24	Nasopharyngitis (16) Depression (11) Falls (10) Headaches (31) Abnormal hearing (36) SI (7)	No statistically significant changes in suicidality symptoms between the active and sham rTMS groups. Remission rate was 39%, with no significant difference between groups.
Zapf et al., 2024	RCT	N=158 Once daily TMS arm (n=82) Mean age: 42.1 (SD=11.2), 62% female Twice daily TMS arm (n=76) Mean age: 41.7 (SD=11.2), 63% female Range: 18-59	MDD	TMS: neuronavigated iTBS Location: L dlPFC Frequency: 50Hz (burst), 5Hz (repetition) Pulses: 1200 per session Sessions: 60 Intensity: 120% MT	HAMD + QIDS + BDI-II composites for STB, DARS, Q-LES-Q 1. Baseline 2. Day ten 3. One month	Not reported for this study	Once-daily & twice-daily iTBS groups showed reductions in STB. Remission rates: 10 days: 18.3% in the once-daily vs 25% in twice-daily, 30 days: 32.9% for once-daily and 39.5% for twice-daily. No significant differences between groups.
Zhan et al., 2024	Open-label Trial	N=55 Mean age: 42.8 (SD=15), 71% female	TRD	TMS: neuronavigated LFR rTMS Location: R dlPFC Frequency: 1Hz Pulses: 1200 per session Sessions: 20 Intensity: 120% MT	CHRT 1. Baseline 2. Tenth treatment 3. Twentieth treatment 4. One week post intervention	Not reported for this study	Mean score reduction of 9.1 points, 32.5% decrease in SI scores post-treatment. Response rates: 60% of patients showed improvement in SI.
Zhang et al., 2020	Open-label Trial	N=146 Without SI at BL (n=49) Mean age: 32.7 (SD=25.7), 63.3% adolescent, 49% female With SI (resolved) (n=63) Mean: 43.6 (SD=26.2), 34.9% adolescent, 60.3% female With SI (unresolved) (n=34) Mean age: 49.9 (SD=25.1), 20.6% adolescent, 55.9% female	MDD	TMS: rTMS Frequency, Pulses & Location: 10Hz, 2400, L dlPFC; 1Hz, 1400, R dlPFC, per session Sessions: 10 Intensity: 120% MT	HAMD Item 3 1. Baseline 2. Post intervention	Transient headaches (2) Musculoskeletal discomfort (4)	Response rates: 64.9% experienced resolution of SI after 2 weeks. Remission rates: HF L dlPFC rTMS had a remission rate of 94%, while LF R dlPFC had 50%. Adult remission rates: 65% for LF R dlPFC vs. 57% for HF L dlPFC. Adolescent remission rate: HF L dlPFC 76.7% vs. 55.6% for LF R dlPFC.
Zhao et al., 2023	RCT	N=45 Mean age: 17.20 (SD=2.25) Range: 13-24, 82.2% females	TRD ft SI	TMS: scalp measured iTBS Location: L dlPFC Frequency: 50Hz Pulses: 1800 per session Sessions: 10 Intensity: 80% Active MT	BSI-CV 1. Baseline 2. Post intervention	Scalp discomfort (3) Headache Site discomfort	The BSI-CV score improved significantly in the active iTBS group (mean 44.52 to 40.43, $p<.001$). No significant change in the sham group (mean 44.86 to 44.27, $p>.050$).
Zhao et al., 2024	RCT	N=44 iTBS arm Mean age: 18.59 cTBS arm Mean age: 21.59, Range: 13-40, 75% female	MDD ft SA	TMS: neuronavigated iTBS (L dlPFC) & cTBS (R dlPFC) Frequency: 50Hz Pulses: 90000 total Sessions: 50 Intensity: 100% MT	BSI 1. Baseline 2. Week one 3. Week three 4. Week five	Site discomfort (3) Fatigue Hypomania (1) * 1 withdrew due to hypomania, 3 withdrew due to site discomfort	a-cTBS showed larger reduction in SI vs. a-iTBS. Mean change at weeks 1, 3, & 5: 50.91%, 40.72%, & 42.99% for a-cTBS, & 26.67%, 28.88%, & 21.71% for a-iTBS.

***Note**:* TMS: Transcranial Magnetic Stimulation*;* rTMS: Repetitive TMS; iTBS: Intermittent Theta Burst Stimulation; cTBS: Continuous Theta Burst Stimulation; aTBS: Accelerated Theta Burst Stimulation; RCT: Randomized Controlled Trial; BD: Bipolar Disorder; PTSD; Post-Traumatic Stress Disorder; MDD: Major Depressive Disorder; TBI: Traumatic Brain Injury; SI: Suicidal Ideation; SA: Suicide Attempt; dlPFC: dorsolateral prefrontal cortex; dmPFC: dorsomedial prefrontal cortex; HAMD: Hamilton Depression Rating Scale; SSI: Scale for Suicidal Ideation; BSI: Beck Scale for

Suicidal Ideation; BHS: Beck Hopelessness Scale; BDI: Beck Depression Inventory; C-SSRS: Columbia Suicide Severity Rating Scale; IDS: Inventory of Depressive Symptomatology-Self Report; PHQ-9: Patient Health Questionnaire; BSL-S: Borderline Symptoms List – Short version; CGI-BPD: Clinical Global Impression for BPD; BEST: Borderline Evaluation of Severity over Time; HAMA: Hamilton Anxiety Rating Scale; BIS: Barratt's Impulsivity Scale; CDRS-R: Children's Depression Rating Scale – Revised; SIOSS: Self-Rating Idea of Suicide Scale; VAS: Visual Analog Scale for SI; MADRS: Montgomery-Asberg Depression Rating Scale; CGI-S: Clinical Global Impression – Severity; ATHF: Antidepressant Treatment history Form; Q-LES-Q: Quality of Life Enjoyment and Satisfaction Questionnaire; QIDS-SR16: Quick Inventory of Depressive Symptomatology – Self Report; CHRT: Concise Health Risk Tracking; DARS: Dimensional Anhedonia Rating Scale;

TMS to the prefrontal cortex (PFC)

Forty-one of the identified studies targeted the PFC with TMS for STB. See Table 2 for an overview of TMS protocols and outcomes for STB.

rTMS applied to the left dlPFC for reducing STB

Of the 41 studies which targeted the PFC, 36 targeted the left dlPFC. Twenty-three of these implemented rTMS protocols, with frequencies between 5Hz-20Hz (Aaronson et al., 2024; Abdelnaim et al., 2019; Bloch et al., 2008; Bozzay et al., 2020; M. H. Chen et al., 2022; Croarkin et al., 2018; Dai et al., 2022; Davila et al., 2019; George et al., 2014; Hadley et al., 2011; Hines et al., 2022; Huang et al., 2025; Keshtkar et al., 2011; Mehta et al., 2022; Ozcan et al., 2020; Pan et al., 2018; Pan et al., 2023; Sun et al., 2024; Wall et al., 2011; Wang et al., 2022; Wang et al., 2024; Weissman et al., 2018; Yesavage et al., 2018; Zhang et al., 2021). Left dlPFC rTMS reduced STB symptoms, with improvements noted in all but two studies (Bloch et al., 2008; Weissman et al., 2018). Specifically, rTMS response rates for STB were indicated between 40-100% (Aaronson et al., 2024; Croarkin et al., 2018; Dai et al., 2022; Hadley et al., 2011; Wang et al., 2022; Wang et al., 2024; Zhang et al., 2021). Further, studies indicated remission rates between 39-94% (Aaronson et al., 2024; Bozzay et al., 2020; Croarkin et al., 2018; Davilla et al., 2019; Mehta et al., 2022; Wang et al., 2018; Yesevage et al., 2018; Zhang et al., 2020).

Additionally, of the 36 studies which targeted the left dlPFC, 13 studies implemented TBS protocols (iTBS, cTBS and aTBS), all of which used 50Hz frequency, some with 5Hz repetitions (Baeken et al., 2017; Baeken et al., 2019; M. H. Chen et al., 2022; Desmyter et al., 2016; Huang et al., 2025; Kong et al., 2023; Li et al., 2024; Mehta et al., 2022; Tang et al., 2021; Wilkening et al., 2022; Zapf et al.,

2024; Zhao et al., 2024; Zhao et al., 2023). All TBS studies indicated improvements to STB. However, (Baeken et al., 2017; Baeken et al., 2019) noted that while there were improvements to STB across active and sham arms, the iTBS group (p=.06) did not show significant improvements compared to sham (p=.03). Of the TBS studies that provided response rates, 62-93.33% responded to treatment (Kong et al., 2023; Tang et al., 2021; Wilkening et al., 2022). Some TBS studies also indicated remission in 18.3-63% of participants (Kong et al., 2023; Mehta et al., 2022; Zapf et al., 2024). However, one study also indicated that STB worsened in 17% of participants (Wilkening et al., 2022).

Three studies reported the use of dTMS applied to the left dlPFC at a frequency of 10-20Hz (Berlim et al., 2014; Hickson et al., 2024; Thai et al., 2024). All studies indicated improvements to STB symptoms during and at completion of treatment, with Berlim and colleagues (2014) also indicating response in 70.6% of participants, and remission in 41.2% of participants.

Right dlPFC

Six studies targeted the right dlPFC, four of which used low frequency (LF) 1Hz rTMS (Rao et al., 2019; Terpstra et al., 2023; Zhan et al., 2024; Zhang et al., 2021) and the remaining used TBS at a frequency of 50Hz (Petrosino et al., 2020; Zhao et al., 2024). The LF rTMS studies identified significant improvements in STB, however Rao and colleagues (2019) did not find significant group differences between the active arm and the sham arm. One study indicated a LF rTMS response rate of 60% (Zhan et al., 2024) while remission rates were 50-55.6% in another (Zhang et al., 2021).

The right dlPFC TBS studies both identified improvements in STB. Further, Zhao et al. (2024) used cTBS, finding it to be superior in reducing STB than left dlPFC iTBS. Futher, Petrosino et al. (2020) found that iTBS treatment for four weeks was superior to treatment for two weeks, with the two-week iTBS group more likely to have STB relapse and do so sooner than the four-week group.

Bilateral dlPFC

Two studies used rTMS to bilaterally target the dlPFC (Adu et al., 2023; Weissman et al., 2018). Both studies applied 1Hz to the right dlPFC, and 10Hz to the left dlPFC, at 100-120% MT. Weissman et al. (2018) found bilateral rTMS reduced STB in the active treatment arm, and this differed significantly to the sham arm (p=.020) and differed to their null finding for left dlPFC rTMS."Treatments for the Prevention and Management of Suicide" (2019) found bilateral dlPFC rTMS reduced STB by 41%, which aligned closely with the 40.4% identified by Weissman et al. (2018) Remission was 25.8% for bilateral dlPFC rTMS (Weissman et al., 2018).

dmPFC

One study investigated rTMS applied to the dmPFC, at a frequency of 5Hz (Calderón-Moctezuma et al., 2020). This study did not identify differences in STB after treatment across the active arm and sham arm, and did not report significant differences in STB within groups.

Left, Right and Bilateral PFC

The retrospective study conducted by Abdelnaim et al. (2019) also investigated rTMS applied to the PFC more broadly. In addition to this, they report use of TMS to

target the ACC, likely through dTMS. While their study indicated 47% showed STB improvement, 41.3% no STB change, 11.7% worsened STB, with one completed suicide during treatment, the results for each region were not independently reported, and interpretation of TMS efficacy at individual target sites was not possible.

TMS to the prefrontal lobe (PFL)

Left PFL

One study investigated rTMS to the left PFL, at a frequency of 10Hz (Dai et al., 2020). They identified that left PFL rTMS had a significant reduction to STB at two (p<.050) and four weeks (p<.010). They also identified that the active arm had stronger reductions to STB than the sham arm, at both timepoints.

TMS to the left primary visual cortex

One study investigated iTBS applied to the left V1 at a frequency of 50Hz (Kong et al., 2023) STB decreased, with an 89% response rates, and a 71% remission rate. They found iTBS targeting the left V1 to be superior to that of the left dlPFC, although the difference was not significant.

Safety and Adverse Outcomes

Of the adverse events (AEs) reported, most were mild, transient and ultimately benign. Most common AEs included headaches (17 studies), dizziness (7 studies), discomfort or pain at the treatment site on the scalp (18 studies), or other mandibular and cephalic symptoms such as tooth pain (3 studies), jaw pain (2 studies), eye twitching/pain (2 studies), and changes to hearing (1 study) or vision (1

study). Three studies reported hypomanic episodes, although the studies were unclear on the pathogenesis (Bloch et al., 2008; Pan et al., 2023; Zhao et al., 2024). Notably, one participant experienced a syncopal event (Thai et al., 2024), and another experienced a seizure, the latter due to imprecise head-coil placement (Hickson et al., 2024). Finally, one study reported a case of second-degree burns as the result of improper TMS administration (George et al., 2014). Overall, the low number of significant AEs (.0009%) suggests that TMS is a low-risk treatment option when appropriate safety protocols are adhered to.

Table 2.

TMS Protocols and Outcomes for STB

Protocol Type	STB Outcomes	Response Rate	Treatment Duration
Accelerated (aTMS/TBS)	Demonstrated significant and rapid decreases to suicidality	Up to 100% response	1-2 weeks
cTBS	Found to be superior to iTBS in one study for suicidality	72.73% remission	1 week (a-cTBS)
iTBS*	Found to demonstrate significant decrease in suicidality in multiple studies	65.63 - 93.33% response	1-2 weeks, (some a-iTBS)
dTMS	Found to demonstrate significant decrease in suicidality	41.2 - 70.6% response	4-6 weeks
rTMS (bilateral)	Found to be superior to sham in one study, specifically for bilateral treatment	40.4% remission	3-6 weeks
HFR rTMS*	Found to demonstrate significant decrease in suicidality in multiple studies	64.9% - 97.5% response	2-6 weeks
LFR rTMS	Found to have mixed-results and less efficacy than HFR rTMS	55.6%	2-4 weeks

Note: *High Frequency rTMS targeting the left dlPFC, and iTBS protocols were found to be the most consistent and effective protocols in reducing suicidality across the included studies.

Discussion and Conclusions

This review provides an updated summary investigating the use of various forms of TMS for the treatment of STB in adolescent and adult participants from 45 identified studies. Studies typically recruited individuals experiencing TRD and were treated for this indication, although studies investigating TMS treatment effects were also found for bipolar disorder, borderline personality disorder, PTSD, and TBI. Of the included studies, most were randomized controlled trials, with four retrospective studies and 16 open-label trials or open-label pilots. The left dlPFC was the most common site used for stimulation. In other studies, the left primary visual cortex and ACC were alternate target regions, as well as the PFC, bilateral dlPFC, and right dlPFC. Stimulation intensities were typically delivered at 100-120% of the resting motor threshold, although intensities as low at 80% were also reported (Bloch et al., 2008; M. H. Chen et al., 2022; Huang et al., 2025). Stimulation frequencies varied across studies, ranging from with low-frequency rTMS (1 Hz) to high-frequency rTMS up to 20 Hz. In addition, the number of pulses per session ranged from 400-8000, with heterogeneity in the number of rTMS sessions applied per day, the total number of sessions applied across a course of treatment. A range of outcome measures also used, depending on the conditions being treated. For the purpose of this review examining rTMS's effects on treating STB, the majority of studies measured STB severity using the BSI, SSI and the C-SSRS rating scales.

Included studies generally reported significant reductions in STB, with most reporting between 47-97% response rates, particularly when receiving high frequency rTMS or iTBS to the left dlPFC. Worsening of symptoms was noted in 11.7-17% of participants with MDD in two studies (Abdelnaim et al., 2019; Wilkening et al., 2022), however, Abdelnaim et al. (2019) did not specify which TMS site or

protocol(s) the increase of STB occurred in. The randomized controlled trials demonstrated the most consistent reductions in STB; while in many studies, both sham and active arms experienced decreases in STB, the active arms— particularly when administered to the left dlPFC—often showed superior results (Dai et al., 2022; Dai et al., 2020; Hines et al., 2022; Pan et al., 2018; Zhao et al., 2023). Interestingly, bilateral application of rTMS or iTBS to dlPFC also showed promise (Weissman et al., 2018), as did TMS applied to the visual cortex (Kong et al., 2023). In addition to the changes in STB, there were some differences noted in the efficacy of TMS when utilizing neuronavigation versus the “5cm rule”, with neuronavigated TMS providing more precise targeting of treatment locations, likely accounting for better outcomes (Sun et al., 2024).

It is important to note that some studies utilized TMS as an adjunct treatment to pharmacotherapy (Aaronson et al., 2024; Bozzay et al., 2020; Calderón-Moctezuma et al., 2020; Pan et al., 2018) or CBT (Adu et al., 2023). Other studies allowed for inclusions of individuals who had previous TMS (Abdelnaim et al., 2019) or alternate past treatments (Bozzay et al., 2020). While participants were often ineligible if they had previous ECT or TMS, Pan and colleagues (2018) found active rTMS combined with anti-depressant treatment was more effective than sham rTMS with anti-depressant treatment in reducing STB. . Nonetheless, for those experiencing TRD (49% of included studies), findings supporting TMS’ efficacy and safety for STB are promising for long term management and treatment (Adu et al., 2023; Berlim et al., 2014; Croarkin & MacMaster, 2019; Croarkin et al., 2018; Wang et al., 2022; Wang et al., 2024; Zhang et al., 2021; Zhao et al., 2023). In addition, the number of participants included within each study was heterogenous, particularly when considering the inclusion of open-label pilots (*n*=3 to *n*=332). However, as this

review aimed to update the evidence regarding the safety and efficacy of TMS, particularly across the various existing protocols, inclusion of these studies provided further context to the potential for TMS as a treatment option for those experiencing STB.

Regarding participant demographics, overall, there were more females included than males. This is in keeping with sex differences in prevalence of internalizing disorders such as depression (van Loo et al., 2023). Furthermore, most participants within this review had a mean age between 42-55. Studies have indicated that depressive problems may often follow a “U-shaped” pattern, whereby the are highest in adolescence/young adulthood, stagnate during mid-adulthood, and increase during older adulthood (Sutin et al., 2013).

Strengths and Limitations

We present the most current review of TMS for STB, with a third of the studies published since the last identified systematic review (Aaronson et al., 2024; Adu et al., 2023; Hickson et al., 2024; Huang et al., 2025; Kong et al., 2023; Li et al., 2024; Pan et al., 2023; Sun et al., 2024; Terpstra et al., 2023; Thai et al., 2024; Wilkinson et al., 2023; Zhan et al., 2024; Zhao et al., 2024; Zhao et al., 2023).There are challenges in synthesizing studies with divergent TMS protocols and methodologies, and while we have endeavored to compare outcomes of like-for-like treatments to the best of our abilities, this may be a limitation of the broader TMS literature, and subsequently our review. While our objective was to investigate the potential for TMS to reduce STB, the inclusion of adolescents and adults within this review may be viewed as a limitation. As adolescents undergo significant neurodevelopment, this may augment (or potentially enhance) their receptibility to TMS treatment (Croarkin

& MacMaster, 2019; Thai et al., 2024). As most adolescents who do not receive treatment for depression or STB during their youth often go on to experience lifelong internalizing problems and comorbid conditions, including youth in TMS investigation is critical to the prevention of long-term symptomatology (Colizzi et al., 2020; Thai et al., 2024). Further, most studies excluded individuals that did not indicate passive suicidality and therefore these findings may not be generalizable to individuals experiencing active suicidal ideation with intent.

Implications and Future Directions

Overall, this review suggests that TMS is efficacious in the treatment of STB, within adults and adolescents, with low risk for adverse outcomes. Moreover, TMS appears effective in alleviating STB irrespective of diagnoses of mental and physical health conditions. Key to sound clinical care in populations presenting with STB, astute clinical risk assessment and management are paramount, to ensure patient welfare while consideration and provision of STB treatments are provisioned. In certain instances of high acuity or illness complexity, rTMS may not be an ideal firstline treatment for the primary presenting illness and the comorbid STB. Future research is needed to determine the efficacy of TMS treatment for STB independently. Randomized controlled trials specifically designed to evaluate rTMS' treatment effects on STB as a primary outcome are needed to validate this promising treatment approach. Future research can also investigate alternate TMS treatment sites for STB beyond the PFC, as brain regions implicated in maladaptive emotion regulation, impulsivity, negative urgency and emotional learning, such as the Cognitive Control Network (CCN) and Salience Network (SEN), are strongly implicated in STB (Bruno et al., 2023). In the meantime, the extant literature supports the notion that rTMS

applied to treat TRD or another primary psychiatric disorder where STB is present, that reduction in STB can be achieved.

Supplementary Materials

Search and Screening Criteria

Databases: PubMed and Web of Science

Search Terms:

PubMed: ("transcranial magnetic stimulation") AND (suicid*)

Filters applied: English, Humans.

29/01/25

137 results

Web of Science: Search all fields "transcranial magnetic stimulation" AND suicid*

In English.

Document type: Article, i.e., not review article, meeting abstract, or book chapter

29/01/25

174 results

Total: 311

Screening:

1. Rayyan flagged 162 papers as duplicates (i.e., 81 duplicates) to be checked.
2. Auto-resolved based on exact match of DOI resolved 102 duplicates.
3. 60 resolved in Rayyan.
4. Manual duplicate screen identified with sort by title found one further duplicate where author had edited title to make link to pdf more publicly available.

Total: 229

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