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Neuroimaging Biomarkers of Suicide Risk: A Narrative Review of Cross-Disorder Evidence and Clinical Implications

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Abstract

Suicide is recognized as a deliberate act of self-destruction. A major share of deaths worldwide continues to be caused by suicide, despite a decline in its global rates since 1990. Suicide is commonly associated with psychiatric and chronic medical disorders. Suicide risk is poorly predicted by current clinical assessments. Recently, neuroimaging methods have been increasingly used to identify biological markers. Underlying neural abnormalities linked with suicidal behavior are thought to be reflected by these markers. The present review was performed to summarize cross-disorder evidence

on neuroimaging biomarkers of suicide risk. Their possible clinical applications were also discussed. A structured literature search was performed in PubMed, Scopus, Web of Science, and APA PsycInfo for studies published from 2015 to 2025. Studies involving in-vivo neuroimaging techniques such as MRI, fMRI, DTI, PET, and MRS were included. Clear measures of suicidal ideation, attempts, or suicide death were required. Relevant data were extracted and organized thematically across structural, functional, and molecular categories. Findings were synthesized narratively. Overlapping and disorder-specific neural signatures were identified. Consistent evidence was observed for reduced gray and white matter volumes in the ventromedial and dorsolateral prefrontal cortex, anterior cingulate cortex, insula, hippocampus, amygdala, and thalamus. Altered connectivity between prefrontal control regions and limbic emotion centers was frequently detected. Disruptions in default mode, salience, and executive control networks were also found. Irregularities in serotonergic and dopaminergic activity were shown by PET findings. These irregularities were related to impulsivity and mood dysregulation. These abnormalities were found across several psychiatric disorders. Suicide vulnerability is indicated to potentially arise from shared fronto-limbic dysfunction, rather than disorder-specific pathology. Research is constrained by small samples, methodological differences, and cross-sectional designs. Larger, longitudinal, and multimodal studies are needed in future work. Support from AI and machine learning is required. Prediction accuracy will be improved, and individualized prevention strategies will be enabled. Suicide prevention is potentially transformed into a more precise, brain-based clinical practice by the early detection of neural biomarkers.

Keywords: suicide risk, neuroimaging, biomarkers, MRI, PET, connectivity, psychiatry

Introduction

Suicide is defined as a death-causing act, performed by a person aware of the fatal potential, and is often marked by uncertain intention (1). Hanging, self-poisoning, and firearms use are included among the most common methods (2).

Although a significant global decrease in suicide rates has been seen since 1990, worldwide mortality is still considerably affected by suicide. Differences in suicide mortality are shown across age groups, sexes, genders, and geographic areas. Between 1990 and 2016, a 6.7% increase in total suicide fatalities was observed, resulting in 817,000 deaths in 2016 (3).

After a suicide, the person's friends and family are left to grieve, and the underlying reason for the suicide is sought (4). A traumatic event is experienced by healthcare professionals after a patient's suicide. A range of emotional responses, such as anger, regret, and self-doubt about professional judgment, is prompted. According to existing research on psychiatrists, it is indicated that at least one patient suicide is experienced by the majority during their careers (5).

Research indicates that a decrease in the number of suicide attempts is associated with the adoption of screening and follow-up procedures in healthcare facilities. Patients do not often reveal suicidal ideation without appropriate encouragement. Systematic screening offers a systematic framework to

healthcare professionals. Evidence-based questions are asked, and disclosure is supported with the help of this framework. These people are then linked to counseling, psychiatric, or other support services (6).

Suicide isn't something that happens in isolation; it's usually connected with many psychiatric and physical health problems. Most suicide cases come with underlying psychiatric disorders like depression, substance use, psychosis, anxiety, personality disorders, eating issues, and trauma-related conditions (7). People who live with long-term medical problems like cancer, HIV, multiple sclerosis, epilepsy, or kidney failure also show a higher risk of suicide. This risk gets worse when the weight of having more than one illness builds up (2).

Lately, neuroimaging techniques are getting more popular and are being used more often. They help us understand suicide risk better, both at the individual and population level. These methods revealed different brain changes, structural, functional, and molecular, that relate to suicidal thoughts and behaviors. The main neuroimaging types include structural MRI (sMRI), functional MRI (fMRI), diffusion tensor imaging (DTI), and molecular imaging like PET, SPECT, and Magnetic Resonance Spectroscopy (MRS). It's important to mention that sMRI shows changes in grey and white matter volume, especially in the prefrontal cortex, anterior cingulate, and temporal areas (8).

Reduced volumes in these regions are indicated by research to be correlated with an increased suicide risk. This is noted particularly among individuals with a family suicide history (9). Atypical connectivity and activation patterns have been identified by fMRI. These patterns are in brain networks linked to emotion regulation, impulse control, and decision-making. Modifications in the ventral and dorsal prefrontal cortex, the insula, and their neural connections are suggested to be associated with the progression from suicidal ideation to attempts (8,10). By DTI's assessment of white matter integrity and connectivity, alterations in tracts were shown by individuals at risk. These tracts were within networks associated with emotional processing and cognitive control (11). While glutamatergic and GABAergic pathways are being explored by MRS investigations, disruptions in the serotonergic system have been identified by PET and SPECT as a potential biomarker for suicide risk (12,13).

Biomarkers within specific diagnostic categories, like major depressive disorder, bipolar disorder, or schizophrenia, have been the predominant focus of most studies. Data integration across these conditions has been neglected. A continuation of this limitation is seen despite significant progress in neuroimaging research on suicide risk. The understanding of whether neurobiological indicators of suicidality are disorder-dependent or transdiagnostic is constrained by this disorder-specific approach. Potential shared neural pathways that explain suicide vulnerability are hidden by a focus only on individual conditions. This is important, as suicidal thoughts and behaviors often go beyond conventional diagnostic boundaries. Consequently, a comprehensive synthesis of cross-disorder research is needed (10). This synthesis is required to identify convergent neuroimaging biomarkers, distinguish between shared versus distinct pathways, and support more effective, diagnosis-

independent clinical prediction and intervention strategies. To encourage a unified, scientifically grounded understanding of suicidality, this gap is addressed by our study. Neuroimaging biomarkers associated with suicide risk are systematically examined across a range of mental disorders.

The potential clinical implications of neuroimaging biomarkers associated with suicide risk across various disorders are analyzed in this paper.

Methodology

The purpose of this narrative literature review was to determine neuroimaging biomarkers of suicide risk in a variety of psychiatric disorders. Four large databases, including PubMed, Web of Science, Scopus, and APA PsycInfo, were searched to include studies published between January 2015 and September 2025. Search terms included combinations of keywords and MeSH headings, such as: “suicide risk,” “suicidal ideation,” “suicide attempt,” “neuroimaging,” “Magnetic Resonance Imaging (MRI),” “fMRI,” “DTI,” “PET,” “MRS,” “biomarkers,” and “functional connectivity.”

Relevance screening was done on titles and abstracts, and full texts of potentially eligible studies were reviewed. All studies were assessed to include them, and the main data were obtained, including sample characteristics (sample size, age range, diagnostic group), neuroimaging modality, brain regions or networks studied, main findings concerning suicide risk, and study design.

Inclusion criteria required that the studies report original human research that used in vivo neuroimaging methods, including MRI, fMRI, DTI, PET, MRS, MEG, or EEG; assess suicide risk through ideation, attempts, or completed suicide; and provide quantifiable relationships between neuroimaging results and suicidality. The eligible designs were observational and interventional studies, such as case-control, cohort, and cross-sectional studies, and postmortem studies to gain mechanistic understanding, and single case studies to gain clinical understanding. Contextual reviews or expert commentaries were consulted but not included in the main synthesis. The studies that did not have explicit measures of suicidality, lacked methodological description, or were not related to pharmacological or animal models were excluded.

Since the literature was methodologically heterogeneous, the synthesis of findings was qualitative. The biomarkers related to structural, functional, and connectivity domains were arranged in themes and cross-referenced across diagnostic categories to explain transdiagnostic patterns. This analytic approach enabled the discovery of uniform neuroimaging patterns associated with suicide risk, and at the same time, it explained the variability in study designs and populations.

Discussion

Neuroimaging research has provided many crucial pieces of evidence of changes in the brain chemistry that take place in such patients, which can potentially serve as biomarkers preceding Suicidal Ideation (SI). Some of these techniques, such as the MRI, were used not only to identify structural changes in the brain (sMRI) but also functional abnormalities (fMRI).

Structural Neuroimaging Biomarkers

sMRI has consistently revealed across various studies abnormalities in Grey Matter Volume (GMV), cortical thickness, as well as White Matter Volume (WMV) in regions that are involved in emotional regulation, cognitive control, and decision-making among patients with psychiatric disorders such as Major Depressive Disorder (MDD), Bipolar Disorder (BD), and Schizophrenia. Neuroimaging studies indicate that structural deficits and disruptions in the regions encompassing the Prefrontal cortex (PFC), anterior cingulate cortex (ACC), insula, amygdala, and thalamus, which form part of the fronto-limbic and cortico-striatal network responsible for emotion and executive processing, tend to become factors for suicide vulnerability (10).

Reductions in GMV and WMV within the ventromedial (VMPFC) and dorsolateral PFC (DLPFC) are associated with impaired decision-making, emotional dysregulation, and vulnerability to suicidal ideation (SI) (10,14). In a study conducted by Campos et al. (2021), results suggested that suicide attempts in depressed patients are associated with volumetric reductions within the thalamus, right pallidum, and surface area reductions in the left inferior parietal lobe (15).

It was found by Liu et al. (2025) that the integrity of white matter in several brain regions was significantly lower in patients with Major Depressive Disorder (MDD) compared to healthy controls. The damage involved multiple major pathways, such as the association fibers (e.g., the uncinate fasciculus and superior longitudinal fasciculus), commissural fibers (e.g., the genu of the corpus callosum), and projection fibers (e.g., the anterior and posterior corona radiata), which means that the structural connectivity of the brain was disrupted on a large scale (16).

The loss of hippocampal volume is a common finding in MDD and in people with suicidal ideation, which is evidenced by the recent MRI study of graduate students with MDD and suicidal ideation (17). The findings of the amygdala are more diverse; some studies report volumetric losses, whereas others focus on functional hyperresponsivity, which can be accompanied by structural alterations (18,19).

Functional Neuroimaging Biomarkers

Resting State fMRI

Across disorders, resting state fMRI consistently revealed reduced connectivity between prefrontal regions responsible for regulation and limbic structures, particularly the amygdala and hippocampus. Multiple studies have found disrupted connectivity within the default mode network (DMN) in individuals experiencing suicidal ideation, including weakened connectivity both within the DMN itself and between the DMN and other networks such as the salience and executive control networks. These disruptions are associated with increased rumination, impaired self-referential processing, and deficiencies in emotion regulation (19,20).

Task-Based fMRI

The study by Fattahi et al. (2025) using the Raven Progressive Matrices task showed a reduction in the activity of three brain regions, namely the ACC, medial superior frontal cortex (SFC), and precentral gyrus, in patients with MDD who had a history of suicide attempt. The left medial SFC hypoactivation can impair the cognitive control systems of suicidal impulses, resulting in poor cognitive control, decision uncertainty, and errors in responses, which subsequently can impair problem-solving and decision making (17).

PET Findings

PET research offers valuable information on the neurochemical dysfunction associated with suicidality, with serotonergic and dopaminergic systems being disrupted. Specific studies of the serotonergic system show that there are regular abnormalities in serotonin receptors and transporters in comparison with the dopaminergic system (21).

Recent PET and postmortem studies, which were done, show a lower serotonin transporter (SERT) binding in the prefrontal cortex and midbrain/brainstem of those individuals with suicidal ideation or suicide attempts, mainly among those individuals with major depressive disorder (MDD), compared to the non-attempters (22–24). Lower midbrain serotonin transporter binding potential in depressed individuals who are likely to commit suicide is linked to Cross-sectional studies, and higher serotonin1A (5-HT1A) receptor binding in the raphe nuclei was likely to be linked with more severe suicidal ideation and more lethal suicide attempts (12).

PET and postmortem studies also reveal that dopamine transporter (DAT) binding is reduced in the midbrain of people with MDD in comparison with healthy controls (25). Anhedonia may be caused by disruption of the reward system in the brain that is in charge of pleasure-seeking behaviors due to decreased DAT in geriatric depressed populations, which is caused by the nucleus accumbens and putamen (26).

Connectivity and Network-Based Biomarkers.

The thoughts and actions of suicide are strongly associated with alterations in numerous neural circuits, which are suggestive of the disturbance of the brain network connectivity (10). Studies conducted on in-vivo connectivity have always demonstrated that the failures of the executive control, salience, default mode, and fronto-limbic networks are the basis of the failures in the emotional regulation and impulse control, which consequently lead to the emergence and escalation of suicidality (10).

Executive Control Networks.

According to the findings of the task-based and resting-state fMRI studies, Schmaal (2020) found that reduced coherence in the executive control network was a hallmark feature of suicidal ideation and behavior. The depressed individuals have been found to have reduced activation in the Dorsolateral

Prefrontal Cortex (DLPFC) and Dorsal Anterior Cingulate Cortex (DACC), which are considered to be the main areas of cognitive control and monitoring of motivational outcomes, and are linked to impulsive decision-making and ineffective assessment of motivational consequences (10).

Fronto-Limbic Networks

The impulsivity and affective instability in suicidal individuals are always linked to disruption in the fronto-limbic circuitry that involves prefrontal regulatory areas and subcortical limbic systems. Specifically, the damage to the Ventral Prefrontal Cortex (VPFC) and its links with limbic systems such as the amygdala and hippocampus suppresses emotional control, making one more susceptible to negative mood states, which may result in suicidal ideation (10,27). Diffusion Tensor Imaging (DTI) studies of white matter integrity indicate that lower Fractional Anisotropy (FA) of fronto-limbic tracts is associated with lower connectivity and increased susceptibility to suicidal behavior (10,28). It is thought that these changes in fronto-limbic functioning are the basis of emotional dysregulation, impulsivity, and the tendency to engage in suicidal behavior in a range of psychiatric disorders.

Salience and Default Mode Networks.

Malfunctions in the Salience network, which is essential in identifying emotionally significant stimuli, and the Default Mode network (DMN), which is essential in self-reflective processing, have a strong relationship with suicide risk in diverse clinical groups. Research shows that hyperconnectivity of the insula to the salience network causes overreaction to negative internal stimuli and impulsivity in people with suicidal thoughts and behaviors (10,27). The combination of these changes in DMN connectivity, particularly in the Posterior Cingulate Cortex (PCC), is thought to establish a process through which poor integration of internal emotional signals with executive processing may lead to the transition between suicidal ideation and behavior (10).

Neuro-developmental and Psychiatric Populations: Connectivity.

Neuroimaging data on developmental stages and psychiatric diagnoses show that there are stable patterns of impaired network connectivity linked to suicidality. In teenagers, lower coherence of executive and fronto-limbic networks is similar to that of adults, indicating the presence of early-developing weaknesses in emotional and cognitive control (10,29). In disorders like Major Depressive Disorder, Bipolar Disorder, and Borderline Personality Disorder, impaired integration in Fronto-limbic and Default Mode Networks is associated with affective instability and impulsivity, which are fundamental characteristics associated with suicidal thoughts and behaviors (27,28). These overlapping changes suggest that network-level malfunction can be a shared neurobiological basis of suicidality across developmental and diagnostic lines.

Multimodal Neuroimaging Findings Integration.

Multimodal neuroimaging offers convergent evidence of network-level disruptions of suicide risk. PET scans reveal a decrease in metabolic activity of prefrontal areas, which is an indication of neurotransmitter dysregulation in serotonergic and dopaminergic systems (10). The findings of magnetoencephalography (MEG) and electroencephalography (EEG) also indicate that there are aberrant temporal dynamics, such as impaired caudothalamic synchrony and abnormal oscillatory activity in emotion-related circuits (27,30). Together, these methods reinforce the conclusion that suicidality is a result of large-scale disturbances in functional connectivity, which is independent of structural and modality-specific differences.

Transdiagnostic Biomarkers

Network-level biomarkers represent a convergent and transdiagnostic substrate underlying suicidal ideation and behavior across many disorders, such as Major Depressive Disorder, Bipolar Disorder, Schizophrenia, Post-Traumatic Stress Disorder, and Borderline Personality Disorder (27). The principal transdiagnostic network alterations identified across psychiatric conditions are summarized in **Table 1**.

Table 1: *Transdiagnostic Network Alterations Associated With Suicidal Ideation and Behavior Across Psychiatric Disorders*

Section	Focus / Network	Key Brain Regions	Main Findings	Linked Psychiatric Disorders	References
Shared Network Alterations Across Psychiatric Conditions	Default Mode Network (DMN)	Posterior Cingulate Cortex, Medial Prefrontal Cortex	Decreased connectivity within the DMN; disturbances in self-referential processing and integration of affective information with cognitive control	Major Depressive Disorder, Bipolar Disorder, Schizophrenia, PTSD, Borderline Personality Disorder	(10)
Convergence in Fronto-Limbic and Salience	Fronto-Limbic Circuitry and	Ventrolateral Prefrontal Cortex, Orbitofrontal Cortex,	Reduced prefrontal regulation over limbic regions; decreased gray	Major Depressive Disorder, Bipolar Disorder, Schizophrenia,	(10,27,28,39)

Network Dysfunctions	Salience Network	Amygdala, Insula	matter volume; disrupted effective connectivity (DTI/fMRI); increased insular activity linked to impulsivity, emotional dysregulation, and sensitivity to negative affect	PTSD, Borderline Personality Disorder	
Implications for Dimensional Models of Suicidality	Executive, Salience, and Default Mode Networks	—	Network abnormalities correspond to cognitive inflexibility, impulsivity, and affective dysregulation; support for dimensional RDoC framework; machine learning models integrating neuroimaging and clinical data improve predictive accuracy	Transdiagnostic (across psychiatric disorders)	(10,30,40,41)

Note. This table summarizes shared neural alterations across multiple psychiatric disorders associated with suicidal ideation and behavior. Findings highlight overlapping dysfunctions in the default mode, fronto-limbic, and salience networks, supporting a dimensional and cross-diagnostic model of suicidality (10,40).

Clinical Implications

Identifying neurological biomarkers for suicidal behavior is critical for preventing suicides and improving patients' mental health. Many patients who attempt suicide deny suicidal ideation before it happens. Traditional clinical assessments mostly fail to predict suicidal risk (31).

Neuroimaging biomarkers have shown strong evidence for improving suicide risk stratification by distinguishing individuals who are more likely to act on suicidal thoughts from those who experience suicidal ideation alone. Such evidence from structural and functional neuroimaging studies in adolescents and young adults demonstrates that suicide attempters show abnormalities in the cerebellum, hippocampus, amygdala, lateral orbitofrontal cortex, temporal gyrus, connection between the latter two, compared to healthy individuals. In contrast, non-attempting suicidal ideators show similar but less pronounced alterations, particularly within the cerebellum, hippocampus, and amygdala (32). Recent multimodal neuroimaging research by Stanley et al. (2021) has identified two neurobiologically distinct suicidal subtypes: a stress-responsive, impulsive type characterized by increased cortisol levels, reactive aggression, and reduced prefrontal inhibitory control, and a cognitive control or planned type marked by sustained serotonergic dysregulation (33).

The END (emotional pain and social disconnect) model suggests that suicidal behavior in adolescents is a result of aberrations in two interacting neural circuits - the emotional pain circuit and the social disconnect circuit. A combination of genetic predisposition and stressful life events causes emotional pain. It stimulates the cerebellum, amygdala, and hippocampal areas, which are engaged in suicidal ideators and attempters to varying extents. The social disconnect is defined by the anomalies of the lateral orbitofrontal cortex, temporal gyri, and their frontotemporal connections; the probability of the transition of ideation to attempt is high (32). Early detection of such neural changes using neuroimaging can be used to detect adolescents who are at high risk before behavioral changes are noticed. Moreover, these results can be used to develop individualized treatments that can address particular neural pathways related to suicidality. As an example, interventions that focus on restoring social connectedness, including interpersonal psychotherapy in adolescents and neurocircuitry-based interventions (similar to TARA) that target the hyperactive amygdala and attempt to reduce or normalize this hyperactivity through mindfulness, emotion regulation, and breathing exercises (32).

Limitations

The existing limitations to the evidence of neuroimaging biomarkers of suicidality are small samples, cross-sectional designs, and heterogeneous methods. Small samples reduce the statistical power, limit the extrapolation of the results, and increase their susceptibility to variability. Most neuroimaging studies, including the EEG-based study by Ozger et al. (2023), are limited by the small sample size and cross-sectional nature (34). Furthermore, a cross-sectional design will not permit making conclusions about the correlated relationships between observed changes in the brain and suicidal behaviors (35).

Ethical considerations

Ethical use of neuroimaging biomarkers in research and clinical practice should be balanced between scientific advancement and the safety of the subjects. Informed consent, confidentiality, and disclosure of results can be a major ethical concern in observational neuroimaging studies in children and adolescents because of neurological abnormalities or other clinically significant observations. The principles of autonomy, beneficence, non-maleficence, and justice guided the Adolescent Brain and Cognitive Development study and provided clear instructions on how to find and overcome potential risks. They include the management of dangerous substance use cases. detection of neurological abnormalities and the threat of self-harm or harm to others (36).

Future directions

Future research should consider longitudinal designs and advanced AI and machine learning methods to enhance predictive models of suicidal behavior. The dynamics of the brain can be understood through longitudinal studies and can predict the transition between suicidal ideation and attempters. A recent study has determined that the psychological and biological biomarkers were far more predictive than single timepoint data. It helps to identify individuals who are at risk of suicide before the crisis. The emergence of multimodal imaging, AI, and machine learning proves a bright future for suicide risk prediction. Integration of unimodal predictions into multimodal models has been demonstrated to be more precise, with a maximum sensitivity of 80 percent in suicide attempt detection (37). Machine learning models have been found to be more effective in predicting suicidal behaviors, particularly in detecting suicide attempts, and are more sensitive than traditional assessment tools.

It is recommended that future research should also encourage the use of standardized neuroimaging protocols and uniform suicide risk assessments across psychiatric disorders, which provide more reliable cross-disorder comparisons (38). Such research could help clarify whether the neural circuits implicated in suicidality are shared across mental illnesses or represent disorder-specific patterns. It ultimately improves our understanding of suicide risk mechanisms.

Conclusion

Overall, accumulating evidence from structural and functional neuroimaging as well as molecular imaging studies identifies a number of strong and reproducible biomarkers linked with suicide risk in psychiatric disorders. Structural MRI is most reliably related to a reduction in grey matter and white matter volume in the ventromedial PFC and dorsolateral PFC, including ACC, insula, amygdala, thalamus, and hippocampus. These are associated with impaired decision making, emotional dysregulation, which leads to increased suicide risk. Functional neuroimaging studies also show reduced corticolimbic connectivity between prefrontal regulatory areas and limbic areas, along with disrupted connectivity within and between the default mode network. PET studies also strongly support the data by disruption of the dopaminergic and serotonergic system, explaining mood variability in impulsivity.

The most consistent findings involve disruption in the fronto-limbic system, Salience and Default Mode Networks, executive control network, which lead to the development and progression of suicidality. Network-level biomarkers represent convergent and trans diagnostic substrates underlying suicidal ideation and behavior across disorders such as major depressive disorder, bipolar disorder, Schizophrenia, post-traumatic stress disorders, and borderline personality disorder. fMRI studies, PET studies, DTI, MEG, and EEG findings strongly suggest a correlation between risk of suicidal behavior and the cross-disorder findings. Studies like Research Domain Criteria (RDoC), suggestive of abnormalities within executive, salience, and default mode networks, correspond to symptom dimensions

Currently, the evidences are based on small, cross-sectional samples with heterogeneous methods, which reduces the statistical power, limits the generalizability of findings, and increases the susceptibility to variability. Ethical consideration is also another major problem related to this study, especially in confidentiality. Future studies should include large longitudinal designs with advanced machine learning with higher sensitivity, combined with AI. It is also important to introduce new advanced standardized protocols and suicidal risk assessments.

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