Brain-Derived Neurotrophic Factor (BDNF) in Depression: A Mini Review of Clinical and Preclinical Evidence

Abstract:

Depression is a complex psychiatric disorder that significantly impacts millions of individuals worldwide. Despite advances in our understanding of its neurobiological underpinnings, treatment options remain limited, and not all patients respond adequately to available therapies. Emerging evidence has implicated brain-derived neurotrophic factor (BDNF), a critical regulator of neuronal plasticity, in the pathophysiology and treatment of depression. This review examines the role of BDNF in the brain, its relationship to depression in preclinical and clinical studies, and its potential as a diagnostic and prognostic biomarker and therapeutic target. We discuss the impact of various antidepressant treatments on BDNF, including pharmacological and non-pharmacological interventions. Finally, we address the challenges and future directions in targeting BDNF for depression treatment. By deepening our understanding of BDNF and its relationship with depression, we can move towards more effective and personalized interventions for this debilitating disorder.

Keywords: brain-derived neurotrophic factor, depression, neuroplasticity, biomarker, treatment

1. Introduction

1.1. Background on Depression

"Depression, also known as major depressive disorder, is a prevalent mental health condition characterized by persistent feelings of sadness, hopelessness, and a lack of interest or pleasure in daily activities" (American Psychiatric Association [APA], 2013). According to the World Health Organization (2021), "depression is a leading cause of disability worldwide, affecting over 260 million people". "The etiology of depression is multifactorial, involving a complex interplay between genetic, environmental, and psychological factors" (Kendler et al., 2002; Levinson, 2006). "Major depressive disorder is a debilitating disorder affecting millions of people each year. Brain-derived neurotrophic factor (BDNF) and inflammation are two prominent biologic risk factors in the pathogenesis of depression that have received considerable attention" (Porter and Connor, 2022; Azman and Zakaria, 2022).

1.2. Neurobiological Basis of Depression

Numerous studies have sought to elucidate the neurobiological underpinnings of depression, with several key findings emerging. At the molecular level, alterations in neurotransmitter systems, including serotonin, norepinephrine, and dopamine, have been linked to depression (Belmaker & Agam, 2008; Nestler et al., 2002). Additionally, neuroinflammation, oxidative stress, and neuroendocrine dysregulation have also been implicated in the pathophysiology of the disorder (Berk et al., 2013; Haroon et al., 2012; Miller et al., 2009).

Increasingly, researchers have focused on the role of neuroplasticity and synaptic dysfunction in the development and maintenance of depression (Duman & Aghajanian, 2012; Duman et al., 2016). Studies have demonstrated reduced hippocampal volume and decreased neurogenesis in both animal models and human patients with depression, suggesting a crucial role for neural plasticity in the disorder (Campbell & MacQueen, 2004; Duman et al., 2001; Sheline et al., 1999).

1.3. BDNF: A Protein of Interest

Brain-derived neurotrophic factor (BDNF) has emerged as a protein of particular interest in the context of depression due to its critical role in supporting neuroplasticity and synaptic function (Autry & Monteggia, 2012; Bathina & Das, 2015). BDNF is a member of the neurotrophin family of proteins, which are essential for the growth, differentiation, and survival of neurons (Huang & Reichardt, 2001). BDNF has been implicated in numerous neurobiological processes, such as neuronal differentiation, synaptic plasticity, and long-term potentiation (LTP) (Bramham & Messaoudi, 2005; Lu, 2003).

A growing body of evidence, encompassing both preclinical and clinical research, has highlighted the relationship between BDNF and depression, pointing to BDNF as a potential biomarker and therapeutic target in the treatment of the disorder (Björkholm & Monteggia, 2016; Hashimoto, 2015). This review aims to synthesize the current understanding of the link between BDNF and depression and to explore the potential implications for diagnosis, prognosis, and treatment.

2. BDNF and its Role in the Brain

2.1. BDNF Synthesis and Release

BDNF is synthesized as a precursor protein, proBDNF, which is cleaved to generate the mature BDNF protein (Seidah et al., 1999). Both proBDNF and mature BDNF are stored in dense core vesicles and secreted in an activity-dependent manner, with their release modulated by neuronal activity and environmental factors (Balkowiec & Katz, 2002; Lessmann et al., 2003). BDNF synthesis and release are regulated by various signaling pathways, including the cyclic AMP response element-binding protein (CREB) pathway, which plays a crucial role in BDNF gene transcription (Tao et al., 1998).

2.2. BDNF Receptors and Signaling Pathways

BDNF exerts its effects by binding to two distinct receptors: the tropomyosin receptor kinase B (TrkB) receptor and the p75 neurotrophin receptor (p75NTR) (Chao, 2003). The binding of BDNF to TrkB receptors initiates several intracellular signaling cascades, such as the mitogen-activated protein kinase (MAPK), phosphoinositide 3-kinase (PI3K), and phospholipase C-γ (PLCγ) pathways, which contribute to neuronal survival, differentiation, and synaptic plasticity (Huang & Reichardt, 2003; Minichiello, 2009). In contrast, binding to p75NTR may lead to cell death or survival, depending on the cellular context and the presence of coreceptors (Reichardt, 2006).

2.3. BDNF and Neuroplasticity

BDNF plays a pivotal role in neuroplasticity, which refers to the ability of the brain to adapt and reorganize its structure and function in response to environmental changes (Poo, 2001). BDNF is involved in various forms of synaptic plasticity, including long-term potentiation (LTP) and long-term depression (LTD), which are essential for learning and memory processes (Bramham & Messaoudi, 2005; Lu et al., 2008). BDNF has also been shown to promote neurogenesis, particularly in the hippocampus, a brain region implicated in depression and cognitive function (Erickson et al., 2010; Scharfman et al., 2005).

3. Preclinical Evidence Linking BDNF and Depression

3.1. Animal Models of Depression and BDNF Expression

Numerous animal models of depression have demonstrated a relationship between BDNF levels and depressive-like behaviors. Chronic stress, a well-established risk factor for depression, has been shown to reduce BDNF mRNA and protein levels in the hippocampus and prefrontal cortex of rodents (Duman & Monteggia, 2006; Smith et al., 1995). Conversely, antidepressant treatments, such as selective serotonin reuptake inhibitors (SSRIs), have been reported to increase BDNF expression in these brain regions (Nibuya et al., 1995).

3.2. BDNF Knockout and Overexpression Studies

Genetic manipulation of BDNF in animal models has provided further evidence for its involvement in depression. Mice with reduced BDNF levels due to heterozygous knockout or conditional knockout exhibit increased depressive-like behaviors, such as anhedonia and behavioral despair (Chen et al., 2006; Monteggia et al., 2007). Conversely, overexpression of BDNF in the hippocampus or prefrontal cortex results in antidepressant-like effects in various behavioral paradigms (Govindarajan et al., 2006; Shirayama et al., 2002). These findings highlight the importance of BDNF in modulating mood-related behaviors and support its potential role in the pathophysiology of depression.

3.3. BDNF Infusion and Antidepressant-like Effects

Direct infusion of BDNF into specific brain regions has further corroborated the link between BDNF and depression. Intracerebroventricular (ICV) or localized infusion of BDNF into the hippocampus, prefrontal cortex, or nucleus accumbens results in significant antidepressant-like effects in rodent models of depression (Hoshaw et al., 2005; Siuciak et al., 1997; Warner-Schmidt & Duman, 2007). These findings suggest that increasing BDNF levels in specific brain regions may be a potential therapeutic strategy for treating depression.

Collectively, these preclinical studies provide substantial evidence for the involvement of BDNF in the development and treatment of depression. The observed alterations in BDNF expression in response to stress and antidepressant treatments, as well as the behavioral consequences of BDNF manipulation, underscore the importance of BDNF in the neurobiology of depression. Future research should continue to explore the molecular and cellular mechanisms through which

BDNF exerts its effects on mood and behavior, with the ultimate goal of developing novel, BDNF-targeted therapies for depression.

4. Clinical Evidence Linking BDNF and Depression: Implications for Diagnosis, Evaluation, Treatment, and Prognosis

4.1. Peripheral BDNF Levels in Depressed Patients: Diagnostic and Evaluative Potential

Several studies have reported decreased peripheral BDNF levels in patients with major depressive disorder (MDD) compared to healthy controls (Molendijk et al., 2014; Polyakova et al., 2015). Moreover, BDNF levels have been found to be negatively correlated with the severity of depressive symptoms (Bus et al., 2015). This suggests that BDNF levels could potentially be used as a diagnostic biomarker for depression and to evaluate the severity of the disorder. However, further research is needed to establish reliable reference values for BDNF levels, taking into account factors such as age and gender (Suliman et al., 2018).

4.2. BDNF as a Treatment Monitor and Prognostic Indicator

Peripheral BDNF levels have been shown to increase following successful antidepressant treatment, suggesting a potential role for BDNF in monitoring treatment response and predicting prognosis (Molendijk et al., 2014; Yoshimura et al., 2017). However, more studies are needed to confirm these findings and establish standardized methods for measuring BDNF levels in a clinical setting.

4.3. BDNF as a Potential Treatment Option

Given the associations between BDNF and depression, it is possible that modulating BDNF levels or activity could be a novel treatment strategy for depression. Recent research has investigated the potential of ketamine, a rapid-acting antidepressant, to increase BDNF levels and exert its antidepressant effects (Duman et al., 2016; Haile et al., 2019). However, more research is needed to investigate the safety, efficacy, and potential side effects of BDNF-targeted therapies.

4.4. Post-mortem Brain Studies and BDNF Measurement

Post-mortem studies of depressed patients have provided valuable insights into the association between BDNF and depression. A reduction in BDNF protein and mRNA levels has been observed in the hippocampus and prefrontal cortex of depressed suicide victims compared to controls (Kang et al., 2012; Tripp et al., 2012). These findings further support the involvement of BDNF in the pathophysiology of depression. Standardized methods for measuring BDNF levels in brain tissue samples are necessary to validate these findings and better understand the role of BDNF in depression.

4.5. BDNF Gene Polymorphisms and Depression Susceptibility

Genetic studies have investigated the association between BDNF gene polymorphisms and susceptibility to depression. The most widely studied polymorphism is the Val66Met (rs6265) variant, which has been associated with a reduced activity-dependent release of BDNF (Notaras et al., 2015). Several meta-analyses have reported a significant association between the Met allele and an increased risk of depression, particularly in Caucasian populations (Liu et al., 2012; Wang et al., 2018). Further research on the clinical implications of BDNF gene polymorphisms, including their potential role in personalized medicine, is warranted.

5. The Impact of Antidepressant Treatments on BDNF

5.1. Antidepressant-induced BDNF Upregulation

Various classes of antidepressants, including selective serotonin reuptake inhibitors (SSRIs), tricyclic antidepressants (TCAs), and monoamine oxidase inhibitors (MAOIs), have been shown to upregulate BDNF expression in animal models and human studies (Castren et al., 2007; Duman & Monteggia, 2006). This upregulation of BDNF may contribute to the therapeutic effects of antidepressants by promoting neuroplasticity and resilience to stress (Duman et al., 1997).

5.2. Ketamine and Rapid-Acting Antidepressant Effects on BDNF

Ketamine, an N-methyl-D-aspartate (NMDA) receptor antagonist, has demonstrated rapid and sustained antidepressant effects in treatment-resistant depression (Berman et al., 2000; Zarate et al., 2006). Preclinical studies have revealed that ketamine increases BDNF expression and signaling in the hippocampus and prefrontal cortex, which may underlie its rapid antidepressant effects (Autry et al., 2011; Li et al., 2010).

5.3. Non-pharmacological Interventions and BDNF Levels

Non-pharmacological interventions, such as electroconvulsive therapy (ECT), repetitive transcranial magnetic stimulation (rTMS), and exercise, have also been shown to influence BDNF levels. ECT and rTMS treatments have been associated with increased BDNF levels in both animal models and patients with depression (Bocchio-Chiavetto et al., 2006; Gersner et al., 2014). Additionally, physical exercise has been found to enhance BDNF expression and improve depressive symptoms, further supporting the role of BDNF in the treatment of depression (Ernst et al., 2006; Rethorst et al., 2009).

BDNF as a Biomarker and Therapeutic Target in Depression

6.1. BDNF as a Diagnostic and Prognostic Biomarker

The accumulating evidence linking BDNF to the pathophysiology of depression has raised the possibility of using BDNF as a diagnostic and prognostic biomarker. Decreased peripheral BDNF levels have been shown to correlate with the severity of depressive symptoms (Karege et al., 2005), while successful antidepressant treatments tend to increase BDNF levels (Aydemir et

al., 2005; Gonul et al., 2005). Therefore, monitoring BDNF levels may help to guide personalized treatment strategies and evaluate treatment response in patients with depression (Molendijk et al., 2014).

6.2. Strategies for Modulating BDNF Levels in Depression Treatment

Given the importance of BDNF in depression, several therapeutic strategies have been proposed to modulate BDNF levels. In addition to conventional antidepressant treatments, ketamine has shown promise as a rapid-acting antidepressant by increasing BDNF expression and signaling (Autry et al., 2011; Li et al., 2010). Non-pharmacological interventions, such as ECT, rTMS, and exercise, have also been found to enhance BDNF expression and may be particularly useful for patients who do not respond to or cannot tolerate pharmacological treatments (Bocchio-Chiavetto et al., 2006; Gersner et al., 2014; Ernst et al., 2006).

6.3. Challenges and Future Directions

While the potential of BDNF as a therapeutic target in depression is promising, several challenges remain. The complexity of the BDNF signaling pathway and its interactions with other neurotrophic factors and neurotransmitter systems need to be better understood to develop targeted interventions (Rantamaki & Castren, 2008). Additionally, the relationship between peripheral and central BDNF levels and their relevance to depression pathophysiology requires further investigation (Molendijk et al., 2011). Further research on these topics will be essential for the development of novel treatments targeting BDNF and improving patient outcomes in depression.

Conclusion

The role of BDNF in depression has become increasingly evident through preclinical and clinical studies. BDNF signaling plays a critical role in neuroplasticity, and alterations in BDNF expression and function have been implicated in the pathophysiology of depression. The potential of BDNF as a diagnostic and prognostic biomarker, as well as a therapeutic target, offers exciting opportunities for future research and the development of innovative treatments for depression. By deepening our understanding of BDNF and its relationship with depression, we can move towards more effective and personalized interventions for this debilitating disorder.

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