Advances in Research of VR Treatment on Adolescent Bipolar Disorder and Brain Energy Metabolism by PET/CT

Jiale LIAO, Keke MA, Conghui WANG, Xiong CHEN, Chunqi AI*

Mental Health Center, Taihe Hospital (Hubei University of Medicine), Shiyan 442000, China

Abstract This study reviewed the clinical characteristics of adolescent bipolar disorder, the shortcomings of traditional treatment models in a systematical manner, analyzed the application status of virtual reality (VR) technology in mental and psychological diseases, and explored the potential mechanism of VR intervention for adolescent bipolar disorder patients, especially the value of PET/CT in the evaluation of brain energy metabolism. Studies have shown that VR treatment may optimize the neurological function of patients with bipolar disorder by enhancing the prefrontal-limbic system network, regulating the reward circuit and improving the executive function, and show positive changes in the metabolism of key brain areas at the PET/CT imaging level.

Key words Adolescent bipolar disorder, Virtual reality (VR), PET/CT, Brain energy metabolism, Emotion regulation, Cognitive training

1 Introduction

Bipolar disorder (BD) is a kind of mental disorder characterized by the fluctuation of mood level between the two extreme states of mania or hypomania and depression. Its core is that the patient's mood is extremely unstable, often showing a rapid transition from excessive excitement and energy to depression and lack of interest[1]. With the increasing maturity of virtual reality technology, people have found that virtual reality (VR) has unique advantages in providing immersive, interactive and controllable scenes, which can open up new space for the diagnosis, assessment and intervention of mental disorders[2]. Positron emission tomography (PET) combined with CT scan can not only clearly image the anatomical structure of the brain, but also reflect the local energy metabolism level of the brain tissue through the tracer. VR technology can provide personalized emotional regulation, cognitive training and social skills exercises for adolescents with bipolar disorder by simulating the real environment, so as to improve the compliance of intervention and optimize the therapeutic effect. In addition, as an advanced neuroimaging technology, PET/CT can objectively quantify the level of brain energy metabolism and provide an important evaluation index for the neurobiological effects of VR intervention. In this study, we reviewed and empirically discussed the topic of "the clinical efficacy of VR treatment and its impact on brain energy metabolism in adolescents with bipolar disorder", in the hope of laying a theoretical and methodological foundation for the subsequent practice and promotion.

2 Characteristics and current situation of adolescent bipolar affective disorder

Bipolar disorder usually presents with recurrent bipolar "manic (or hypomanic)-depressive" transitions, or a complex clinical course with mixed features. According to the difference of manic degree and course characteristics, it can be divided into bipolar I disorder, bipolar II disorder and cyclothymic disorder[3]. Bipolar I disorder is mainly characterized by obvious manic episodes, and patients may have extreme excitement, excessive words, reduced sleep needs, emotional irritability and other manifestations; the core of bipolar II disorder is to experience at least one obvious depressive episode and one hypomanic episode[4]. Adolescent onset bipolar disorder often develops rapidly, has many complications and high misdiagnosis rate, and easily affects the academic and psychological maturity process of patients[5]. For adolescents in the critical period of physical and mental development, bipolar disorder not only brings about problems such as declining academic performance and social tension, but also may lead to serious consequences such as substance abuse, impulsive behavior, and even suicidal thoughts. Because of the complex psychological and social environment of adolescence, the identification and treatment of bipolar disorder in this population is often more challenging. Traditional treatment mainly relies on drugs (such as mood stabilizers, antipsychotics, antidepressants, *etc.*) and comprehensive interventions such as psychotherapy or family therapy. However, adolescents often have difficulty in tolerating the side effects of some drugs, or have decreased compliance and inadequate adherence to treatment[15-18]. If psychotherapy only stays in the form of traditional face-to-face conversation or homework, it often lacks enough interest and immersion, and it is difficult to effectively attract adolescents to participate continuously.

3 Review of the traditional treatment of adolescent bipolar disorder

At present, medication is the first choice for the treatment of adolescent bipolar disorder[6]. Commonly used drugs include mood stabilizers and antipsychotics. However, for adolescents, some side effects of drugs, such as weight gain, metabolic syndrome and potential effects on neurodevelopment, can lead to a decline in drug compliance of patients and their parents. Besides, the characteristics of the disease course of adolescents determine that their

Received: January 11, 2025 Accepted: March 2, 2025

Jiale LIAO, master's degree. * Corresponding author. Chunqi AI, master's degree, chief physician.

response to drug dosage and treatment duration is different from that of adults, which requires individualized consideration. The second is psychotherapy. Although psychotherapy plays an important role in helping patients identify and regulate emotions and rebuild thinking patterns, the attractiveness and sustainability of traditional psychological interventions may be insufficient without adequate scenario simulation and immediate feedback, especially for adolescents who are easily distracted and lack interest in abstract forms of intervention[7]. The third is that they need good family and social support. Many studies[8] have emphasized the importance of family therapy, family support and social support systems. However, the reality is that many families have limited understanding of bipolar disorder and uneven distribution of social support resources, which leads to the lack of effective psychological and behavioral management environment for adolescents outside treatment, thus making it difficult to consolidate the treatment effect. Generally, the clinical intervention of adolescent bipolar disorder needs to focus on drug, psychological, family and social support, but the existing intervention model is still difficult to take into account the unique needs of the population in terms of cognitive level, behavioral characteristics and interests, and more innovative therapies are urgently needed to make up for the deficiencies.

4 Application of VR technology in mental illness

VR technology is based on computer graphics and sensor interaction technology, which creates an interactive virtual environment for users through head-mounted display, motion capture system or handle and other peripherals[9]. The core value of VR technology lies in "immersion". Under the comprehensive stimulation of multiple senses such as audio-visual and tactile, VR can make users feel personally on the scene and greatly improve the real sense of participation and concentration in the simulated situation[10]. In addition, VR also includes "interactivity". Users can interact with objects in the virtual environment with the help of handles or motion capture devices, so as to achieve a more active and feedback experience. This interactive mechanism can significantly enhance the interest and personalization of the training or treatment process[11]. Finally, the "controllability and repeatability" of VR technology. In VR scenarios, experimenters or clinical therapists can strictly set variables such as scenarios, time, events or stimulus intensity, and can repeat exposure or training under safe conditions, thus effectively avoiding safety risks and uncontrollable factors in real life.

5 Potential advantages of VR technology in the treatment of adolescent bipolar disorder

VR technology can first improve compliance and interest, compared with the traditional "sitting in the clinic dialogue" mode, teenagers tend to be more interested in novel and technological VR treatment. This curiosity and positive attitude towards the experience of technology and immersion may make them more willing to engage in regular and continuous treatment. Secondly, VR technology can provide safe scenario simulation. Adolescents with bipolar disorder are at risk for impulsivity during episodes of mania or agitation[12]. VR environment allows them to safely experience some high-risk scenarios, cultivate the ability of emotional recognition and regulation, and avoid interpersonal conflicts or self-harm caused by emotional uncontrollability in real situations[13]. Thirdly, VR technology has the advantages of data and personalization. VR systems can usually capture multi-dimensional data, such as head movement, operation trajectory, path selection, *etc.*, to provide refined behavioral indicators for interventionists or researchers. In addition, combined with the scale or clinical observation, the intervention process and efficacy can be further accurately evaluated, and the training content of different levels or different emphases can be customized according to the specific conditions of patients. Finally, VR technology can also be integrated with drugs or other psychotherapies. VR is superimposed on the original drug therapy or psychotherapy, making it have better scene and immediate feedback functions, and improving the overall intervention effect.

6 Current status and main findings of PET/CT in bipolar disorder

Firstly, it found metabolic changes in key brain regions of bipolar disorder. Patients with bipolar disorder often have metabolic abnormalities in the prefrontal lobe, limbic system (amygdala, hippocampus, cingulate gyrus) and basal ganglia, which are closely related to emotional regulation[14]. During the manic phase, certain excitation-related pathways or reward pathways may have increased metabolism, while during the depressive phase, there is a general decrease or disorder of metabolism[15]. Secondly, it can distinguish different subtypes and episode stages. Quantitative analysis of PET/CT images can help researchers and clinicians better distinguish patients with mania, hypomania, mixed episode or depression, and stratify different subtypes of bipolar disorder. Thirdly, PET/CT can also be used for efficacy evaluation[16]. PET/CT can also be used to monitor changes in brain metabolism before and after drugs or other therapies, and when the patient's condition improves, there may be a positive correction of metabolic levels in brain areas related to emotional regulation and cognitive function[17].

For the adolescent population, the PET/CT assessment has the following implications. (i) Early identification. When the clinical signs and symptoms is not yet typical or has a high degree of confusion, PET/CT can find early signs of metabolic abnormalities in brain regions, or provide objective support for early differential diagnosis of the disease. From the perspective of neurodevelopment, the adolescent brain is not yet fully mature, and the development of the structure and function of specific brain areas is in a critical period. If a significant interaction between bipolar disorder and brain metabolism is found, it may deepen people's un-

derstanding of the disease at the neurodevelopmental level. (ii) Optimization of intervention strategies. With the help of objective PET/CT data, physicians can more accurately judge the effect of intervention and adjust the treatment plan in time, including the type and dosage of drugs, as well as the focus of psychological or rehabilitation training. (iii) The limitations of PET/CT are mainly reflected in high cost, high requirements for operators and equipment environment, and certain radioactive exposure. As a result, its large-scale application in children and adolescents is still limited, but as a powerful auxiliary tool for research and clinical evaluation, its value should not be ignored.

In summary, as a common and complex mental illness, bipolar disorder has a profound impact on adolescents, and traditional treatment is often limited by the lack of compliance, interest and objective assessment methods. VR technology, with its immersion and interactivity, provides new possibilities for improving existing intervention models. By carrying out emotional regulation, cognitive training and social skills exercises in a safe and controllable virtual environment, adolescent patients have a better chance to gradually master self-regulation strategies in game-based or task-based experience. PET/CT can provide biological support for evaluating the objective efficacy of VR intervention by monitoring changes in brain metabolism, and help clinicians and researchers to better understand the impact of intervention on brain functional networks. However, actually, VR intervention and PET/CT application still face many challenges in practice, such as technology, cost, sample size and long-term effect evaluation, which require larger multi-center studies and more abundant multi-modal data support. In the future, if we can realize personalized VR scene design, fully consider the special physiological and psychological needs of adolescents, and integrate with drugs, traditional psychotherapy and family/social support system, VR and PET/CT are expected to occupy a more valuable place in the diagnosis and treatment system of adolescent bipolar affective disorder, to provide more accurate and comprehensive basis for clinical decision-making and prognosis prediction.

References

[1] FANG H, ZHENG DD, NONG YX, *et al.* Analysis on the changes in the types of diseases of children and adolescents with psychiatric and psychological disorders in the outpatient clinic of a psychiatric hospital in Nanning Guangxi from 2014 to 2023[J]. Chinese Journal of New Clinical Medicine, 2025, 18(1): 77 – 82. (in Chinese).

[2] YAN SS, LI L. Application of home care based on cross theoretical models in patients with bipolar disorder and depressive episodes[J]. Henan Medical Research, 2025, 34(1): 181 – 184. (in Chinese).

[3] DING D. Integration approaches of virtual reality technology in news narration[N]. Beijing Science and Technology News, 2025 – 02 – 10 (005). (in Chinese).

[4] QIU CG, YU SK, LI SY, *et al.* Exploration on the application of virtual reality technology in psychological counseling for higher vocational students[J]. Modern Vocational Education, 2025(5): 153 – 156. (in Chinese).

[5] PENG YH. Innovative application of virtual reality technology in immersive experience design of intelligent cockpits[J]. Auto Time, 2025(3): 135 – 137. (in Chinese).

[6] WANG JY. Research on the application of virtual reality technology in the protection and inheritance of traditional art[J]. Portrait Photography, 2025(2): 167 – 168. (in Chinese).

[7] ZHENG T, FENG XS, ZHANG F, *et al.* Innovative study of virtual reality technology in interaction design[J]. Shoes Technology and Design, 2025, 5(2): 24 – 26. (in Chinese).

[8] TANG QY, ZHOU Q, SHEN J, *et al.* Research progress on measurement techniques, influencing factors and clinical applications of standardized uptake value in ^{18}F-FDG PET/CT imaging[J]. Chinese Journal of New Clinical Medicine, 2024, 17(7): 836 – 840. (in Chinese).

[9] SONG W, ZHANG H, MENG LL, *et al.* The relationship between children and adolescents with bipolar disorder and parenting style and family environment[J]. Journal of International Psychiatry, 2024, 51(5): 1413 – 1416 , 1441. (in Chinese).

[10] SUN ZH, ZHAO JH, LI XH. Analysis of the impact of graded psychological intervention on the negative psychology of hospitalized adolescent patients with bipolar disorder[J]. Psychology Monthly, 2024, 19(18): 176 – 178. (in Chinese).

[11] AI WZ. Construction and verification of a nomogram prediction model for self-harm risk in patients in the remission phase of bipolar disorder[J]. Modern Nurse, 2024, 31(9): 155 – 160. (in Chinese).

[12] WANG CJ, BUHAIQIEMUHAN · WUBULIAISHAN, ZHANG C, *et al.* Study of the effects of repeated rTMS therapy on cognitive function in pediatric and adolescent patients with bipolar depression[J]. Xinjiang Medical Journal, 2024, 54(8): 893 – 896. (in Chinese).

[13] WANG ML, ZOU SH. Research progress on genes related to impulsive and aggressive behaviors in adolescent bipolar disorder[J]. Xinjiang Medical Journal, 2024, 54(8): 902 – 905. (in Chinese).

[14] LU YP, CUI W, ZHANG LL, *et al.* Influencing factors of transition to mania in adolescents with first-episode depressive disorder within six months[J]. Journal of Neuroscience and Mental Health, 2024, 24(11): 761 – 766. (in Chinese).

[15] ZHANG DD, ZHANG LS, WANG J. Efficacy evaluation of quetiapine fumarate in the treatment of manic episodes of bipolar disorder in adolescents[J]. Psychology Monthly, 2024, 19(21): 175 – 177. (in Chinese).

[16] QIDIANGAO. Chinese scientists develop a highly accurate diagnostic method for early-stage bipolar disorder in adolescents[J]. Shanghai Medical & Pharmaceutical Journal, 2024, 45(19): 98. (in Chinese).

[17] DUAN X, LU Y. Application of virtual reality technology in the diagnosis and treatment of mental diseases[J]. Journal of Psychiatry, 2018, 31(4): 316 – 320. (in Chinese).