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ADHD IN YOUNG MINDS: A NEW PERSPECTIVE ON DIAGNOSIS AND MANAGEMENT

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A – study design, **B** – data collection, **C** – statistical analysis, **D** – interpretation of data, **E** – manuscript preparation, **F** – literature review, **G** – sourcing of funding

ABSTRACT

Background: Attention Deficit Hyperactivity Disorder (ADHD) is characterised by three main symptoms: excessive impulsivity, hyperactivity, and difficulty concentrating and maintaining attention. Early diagnosis of ADHD is crucial to ensure timely and appropriate medical intervention.

Aim of the study: The aim of this study is to provide an in-depth analysis of recent research on ADHD in children.

Material and methods: A broad set of MeSH keywords and terms, including ADHD, Attention Deficit Hyperactivity Disorder, diagnosis, and treatment, was used. The search was conducted using the PubMed, Scopus, and Wiley Library databases.

Results: A review of the literature highlights the complexity of ADHD, which requires a multifaceted therapeutic approach. Effective treatment includes pharmacotherapy, such as stimulant and non-stimulant medications, as well as non-pharmacological interventions, including behavioural therapy, iron and probiotic supplementation, and alternative approaches such as yoga and music therapy. The study also emphasised the importance of emerging diagnostic technologies, such as EEG analysis and machine learning frameworks, in improving diagnosis and enabling more personalised treatment.

Conclusions: ADHD requires a comprehensive therapeutic approach that includes early diagnosis, appropriate pharmacotherapy, and behavioural and environmental support. New diagnostic and therapeutic technologies may significantly enhance treatment effectiveness. Further research into pathophysiological mechanisms and the development of personalised therapeutic strategies is needed.

KEYWORDS: attention deficit disorder with hyperactivity, attention deficit hyperactivity disorder, neurodevelopmental disorders, pediatrics

Background

Attention Deficit Hyperactivity Disorder (ADHD) is a complex neurodevelopmental disorder that significantly affects cognitive, emotional, and social functioning. It manifests through three primary symptoms – excessive impulsivity, hyperactivity, and difficulty in sustaining attention – which together

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interfere with a child's ability to function effectively at school, at home, and in peer relationships. ADHD symptoms typically emerge before the age of 12 and may persist into adolescence and adulthood, often leading to lifelong challenges if not properly diagnosed and managed [1].

The global prevalence of ADHD in the paediatric population is estimated to be around 7%, making it one of the most common psychiatric disorders in children [2]. The pathophysiology of ADHD is the subject of extensive research. Current findings indicate associations between the disorder and factors such as genetic abnormalities, toxin exposure, nutrient deficiencies, infections, maternal illness and stress during pregnancy, as well as socioeconomic adversity, including poverty and trauma [3]. The current clinical classification of ADHD distinguishes three types: predominantly inattentive, predominantly hyperactive-impulsive, and combined type. The combined type is the most common presentation, while the predominantly inattentive type is more frequently observed among children born preterm [4–5].

Untreated ADHD is associated with numerous adverse outcomes, including poor academic performance, social rejection, family conflict, and an increased risk of developing mood disorders and conduct problems in adolescence and adulthood. Early diagnosis is essential to ensure that appropriate medical intervention can be initiated promptly. Behavioural therapy combined with pharmacological treatment can improve overall functioning within a relatively short period. An important aspect of ADHD management is its multimodal nature, which includes environmental modifications in addition to pharmacotherapy and behavioural interventions [1–2,6].

Given the high prevalence, complex etiology, and substantial clinical and social implications of ADHD, ongoing research into its mechanisms and management strategies remains a public health priority. Understanding ADHD as a lifelong neurodevelopmental condition rather than a transient childhood issue underscores the importance of early intervention, family education, and a comprehensive therapeutic approach.

Aim Of The Study

The purpose of this study is to provide an in-depth analysis of the latest research on ADHD in children.

Material and methods

Search strategy

The review was based on scientific publications obtained through a comprehensive search strategy. The following MeSH terms and keywords were used: „ADHD" OR „Attention Deficit Hyperactivity Disorder" OR „Attention-Deficit/Hyperactivity Disorder" AND „diagnosis" OR „diagnostic methods" OR „assessment" OR „screening" AND „children" OR „pediatric" OR „child" OR „adolescents" AND „treatment" OR „therapy" OR „management" OR „pharmacotherapy" OR „behavioral therapy" OR „cognitive behavioral therapy". The search was conducted using the PubMed, Scopus, and Wiley Library databases. Abstract-only records, articles not available in Polish or English, and duplicate studies were excluded. Ultimately, forty-four articles in Polish or English were selected, with an emphasis on the most current information available.

Eligibility criteria

Studies meeting the following criteria were included in the systematic review:

1. Population: Children and adolescents (from the neonatal period up to eighteen years of age) diagnosed with attention deficit hyperactivity disorder.

2. Results: Information on etiology, pathophysiology, symptomatology, epidemiology, diagnostic methods, therapeutic options, and treatment outcomes.

3. Language: Publications in English or Polish.

The exclusion criteria were: studies involving adult populations, expert opinions, letters to the editor, conference reports, publications without full-text access, and studies lacking relevant data.

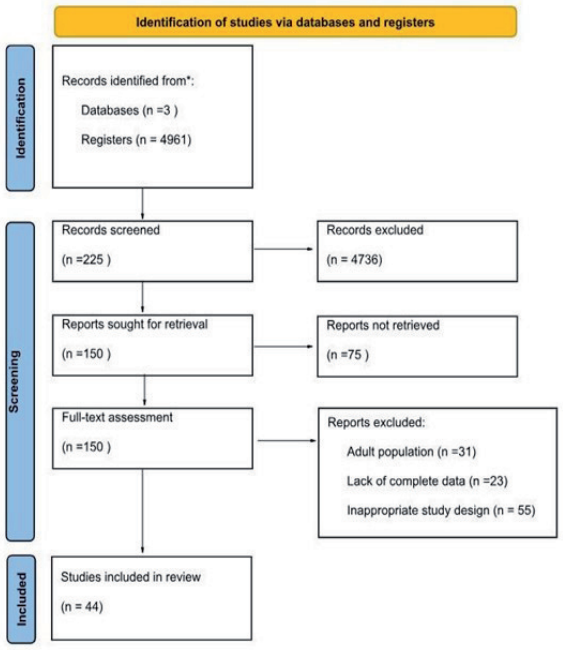

Figure 1. Flowchart demonstrating the identification, screening, and selection of the included studies in this systematic review

Data collection

The literature review was conducted independently by each author. Initially, abstracts of the identified articles were screened to assess their relevance to the topic. Articles that met the inclusion criteria were selected for full-text analysis. These articles were evaluated based on factors such as age groups included, diagnostic methods described, and treatment outcomes reported. The collected data were cross-verified by the authors to ensure consistency and accuracy. The final dataset was organized to provide a comprehensive overview of the current state of knowledge on ADHD in children, highlighting key challenges and recent advancements in this field.

Results

Understanding ADHD and its characteristics

Attention-Deficit / Hyperactivity Disorder (ADHD) is the most common neurodevelopmental disorder diagnosed in paediatric patients [1,4,7]. It is characterised by deficits in cognitive functioning and impaired ability to perform daily tasks, influencing multiple aspects of a patient's life [1,4,7–8]. ADHD can be diagnosed across the lifespan; however, the disorder typically begins in early childhood, before 12 years of age, with symptoms persisting in at least two settings. Importantly, symptoms do not need to be equally prominent at home, school, or work [1,4].

The development of ADHD does not have a clearly defined aetiology; nevertheless, multiple factors have been linked to an increased risk of the disorder. Genetic predisposition plays a role, although no single gene has been identified, and several are believed to contribute to ADHD expression [1,4,9]. The prenatal period is particularly important. Numerous studies have shown correlations between exposure to toxins such as alcohol and nicotine during pregnancy, extreme prenatal stress, and foetal viral infections, all of which increase the risk of ADHD [1,4,10]. A study conducted in the United Kingdom and Norway involving parents and their children demonstrated a positive correlation between parental alcohol and tobacco use and ADHD symptoms in offspring, with maternal exposure showing the strongest association [10]. Conversely, a study analysing 48,072 children born between 1998 and 2012 reported no correlation between alcohol consumption during pregnancy and the development of ADHD, indicating that this topic requires further research [11].

Children born with low birth weight or prematurely (before the 33rd week of gestation) have a 2–3-fold increased risk of ADHD, while those born before the 26th week have a fourfold increased risk compared to full-term infants [1–2,4]. Moreover, socioeconomic adversity and negative life experiences have also been linked to ADHD. A meta-analysis published in 2018 indicated an association between childhood maltreatment and the development of ADHD [12]. The authors highlighted similarities in symptom presentation between maltreated children and those diagnosed with ADHD, complicating clear differentiation between the two groups, while demonstrating a statistically significant correlation [12].

Neuroimaging studies have identified several anatomical differences in the brains of individuals with ADHD, which may affect functional outcomes. These include reduced grey and white matter volumes, a smaller cingulate gyrus, reduced dorsolateral prefrontal cortex size, decreased activity in the frontostriatal region, and reduced dopaminergic and noradrenergic receptor density in the frontal lobe. These abnormalities are associated with impaired goal-directed behaviour and emotional dysregulation [1,4].

ADHD diagnosis is based on the symptoms presented by the patient, which span various psychiatric and neurological domains. The main characteristic is attention deficit, manifested as difficulty maintaining focus on a single task, forgetfulness, losing items, difficulties completing tasks, and impaired decision-making [1,4]. Hyperactivity may present as excessive movement or energy, restlessness, impatience, and behaviour inappropriate for the situation. Impulsivity is reflected in actions undertaken without prior reflection [4]. Paediatric patients with ADHD are 6.2 times more likely to experience nighttime disturbances, and sleep irregularities are common, including insufficient sleep, increased daytime napping, and irregular sleep-wake cycles [8]. Emotional dysregulation is also frequently reported, contributing to additional psychiatric symptoms [1,4,12]. Beyond the core symptoms, many patients exhibit further manifestations that may lead to or overlap with other psychiatric conditions [1,4,12].

The symptoms presented allow for the diagnosis of a specific ADHD subtype. Three main presentations are recognised: Predominantly Inattentive, Predominantly Hyperactive/Impulsive, and Combined presentation [1,4]. The Predominantly Inattentive presentation is characterised by difficulty maintaining focus, completing tasks, lack of precision and organisation, forgetfulness, and susceptibility to losing items such as keys, mobile phones, or school materials [4]. The Hyperactive/Impulsive presentation includes excessive talking, fidgeting, tapping, aimless movement, acting or speaking without prior thought, and interrupting others. The Combined presentation exhibits symptoms from both categories with similar intensity [4].

Epidemiology of ADHD in children

Although adhd – initially described under various names – appears in historical medical literature, its prevalence cannot be reliably assessed prior to the introduction of standardised diagnostic criteria [3]. The term „adhd" first appeared in the second edition of the diagnostic and statistical manual of mental disorders (dsm-ii) as "hyperkinetic reaction of childhood." In dsm-iv, adhd was redefined as a lifespan neurodevelopmental condition, with criteria applicable to both children and adults [13]. Dsm-5 further expanded diagnostic definitions, contributing in part to increased diagnosis rates [14–15].

The current estimated prevalence of ADHD in children is 5–7% [14,16]. This research draws on findings from a comprehensive systematic review and meta-analysis involving 1,837 articles, of which 61 met inclusion criteria. The study found that the prevalence of ADHD in children under 12 years was 7.6% overall, rising to 7.7% when DSM-IV criteria were used. Among adolescents aged 12–18 years, prevalence was 5.6%, and 7.1% using DSM-IV criteria. The same study also calculated the prevalence of ADHD subtypes: 37.3% for the Inattentive subtype, 23.1% for the Hyperactive-Impulsive subtype, and 31.1% for the Combined subtype [15].

ADHD is consistently reported to be more prevalent in males, with ratios ranging from 2:1 to as high as 4–9:1 in various studies [3,14,17]. However, these differences may reflect disparities in symptom presentation rather than true prevalence. Males tend to show more externalising and observable behaviours, while females often exhibit internalising symptoms, increasing the risk of underdiagnosis in girls [14–15].

Diagnostic methods for ADHD

Diagnosing ADHD is challenging because there are no clear biological markers or highly specific symptoms unique to the disorder. Symptoms often overlap with those of other conditions, and ADHD frequently co-occurs with additional disorders, further complicating the diagnostic process [18]. Common comorbidities include learning disorders such as dyslexia and dyscalculia, as well as autism spectrum disorder. Tic disorders, Tourette's syndrome, and obsessive-compulsive disorder are also frequently observed in individuals with ADHD. Other common co-occurring conditions include developmental coordination disorder, depression, anxiety, oppositional defiant disorder, and conduct disorder [19]. Additionally, substance use disorders require attention, as children with ADHD are more susceptible to developing them [1].

One of the most commonly used diagnostic tools is the Diagnostic and Statistical Manual of Mental Disorders, 5th edition (DSM-5). To meet DSM-5 criteria, patients must exhibit at least six symptoms of inattention and/or at least six symptoms of hyperactivity and impulsivity. Based on the predominant symptoms, individuals are diagnosed with one of three ADHD presentations: predominantly inattentive, predominantly hyperactive-impulsive, or combined. Symptoms must be present before the age of 12 and must occur in at least two settings. In young children, this requirement can be difficult to assess and may result in delayed diagnosis [20–21].

ADHD diagnosis integrates clinical observations with subjective reports. In children, this typically includes information from parents and teachers obtained through interviews or questionnaires, alongside clinical evaluations and, in some cases, neuropsychological assessments. However, these methods may be influenced by biases from clinicians and informants, contributing to underdiagnosis or overdiagnosis – particularly in groups such as girls – which may result in inappropriate treatment [22]. Rating scales and questionnaires are useful for gathering information from multiple informants but are insufficient for diagnosing ADHD on their own, as similar symptoms may occur in conditions such as depression, anxiety, sleep apnea, and anemia. Therefore, detailed clinical assessment is essential to avoid misdiagnosis. Despite their limitations, these tools are effective for initial screening, monitoring symptoms over time, and evaluating treatment response.

Clinicians employ various rating scales to assess ADHD symptoms, with recommendations differing between institutions. The latest Canadian ADHD Practice Guidelines recommend the Swanson, Nolan, and Pelham Teacher and Parent Rating Scale (SNAP-IV) as a primary assessment tool. Similarly, the National Institute for Health and Care Excellence (NICE) highlights the usefulness of additional scales, such as the Conners' Rating Scales and the Strengths and Difficulties Questionnaire, especially when diagnostic uncertainty exists. These varied recommendations underscore the necessity of a comprehensive, multimodal approach to ADHD assessment [23–24].

New diagnostic methods are being developed to improve accuracy. One such tool is a variation of the continuous performance test, known as the MOXO-CPT, which incorporates environmental distractions to assess attention, timing, impulsivity, and hyperactivity. A recent study involving 798 children found that those with ADHD scored significantly lower on attention and timing indices and higher on impulsivity and hyperactivity indices compared to controls. While most indices demonstrated strong diagnostic value, impulsivity was less effective in distinguishing ADHD from non-ADHD cases. Nevertheless, the

overall performance of the test suggests that it is a valuable diagnostic aid [22].

Another innovative method involves the use of a medical chair equipped with piezoelectric sensors to objectively analyse movement patterns. A study by Tung-Ming Chang and colleagues found that children with ADHD exhibited significantly higher movement variance, zero-crossing rate, and high-energy movement patterns compared to controls. The strong classification performance suggests that such a "smart chair" may serve as an effective objective tool for ADHD assessment [25].

A 2021 study proposed a machine learning framework that analyses pupil-size dynamics as an objective biomarker for automated ADHD diagnosis. Using advanced classification algorithms, the system identified 218 significant features – such as pupil dilation velocity – that differentiated children with ADHD from controls. Although limited by a small sample size, the findings highlight the potential of pupillometry and machine learning for more accurate, automated ADHD detection [26].

Efforts are also underway to enhance the use of electroencephalography (EEG) in ADHD diagnosis. A recent study by Yasaman Kiani Boroujeni and colleagues employed non-linear EEG analysis using chaotic indices such as the Lyapunov exponent, fractal dimension, correlation dimension, and entropy measures. Involving 50 children with ADHD and 26 controls, the study achieved 98% sensitivity, 92.31% specificity, and 96.05% accuracy, indicating that non-linear EEG features may provide a highly effective diagnostic approach [27]. Another study from 2020 developed an EEG-based diagnostic tool using convolutional neural networks to analyse color-encoded EEG images obtained during a continuous mental task. The model demonstrated high accuracy, outperforming previous methodologies and highlighting the potential of deep learning in early ADHD diagnosis [28].

Neuroimaging research is advancing rapidly, though it is not yet adequate for routine clinical use. A 2021 review by Pereira-Sanchez and Castellanos analysed 40 publications from 2019–2020 and highlighted both progress and limitations in ADHD neuroimaging. While findings from functional and resting-state MRI studies were inconsistent, the ENIGMA consortium identified small but significant structural brain differences between children with ADHD and controls. The review also emphasized the growing use of open-science initiatives, multimodal datasets, and machine learning to better understand ADHD's genetic, environmental, and developmental components [29].

One promising tool to improve neuroimaging-based ADHD detection is the Sparse Wrapper Algorithm (SWAG), presented in a recent study by Yavuz Ozdemir et al. SWAG combines screening and wrapper approaches to generate low-dimensional models with strong predictive power, highlighting brain regions such as the frontal and temporal lobes. It consistently produced accurate results across different machine learning models, offering simpler and more effective feature combinations than traditional methods [30].

Approaches to ADHD treatment

Current treatments for ADHD include pharmacological and non-pharmacological interventions. Pharmacological treatment consists of stimulant and non-stimulant medications, while non-pharmacological approaches include parental education and behavioural therapy, among others [31]. There are clinical differences between pharmacological and non-pharmacological treatments, and potential risks, benefits, costs, and uncertainties should be carefully considered before initiating therapy [6].

Pharmacological treatment

Stimulant medications fall into two main classes: methylphenidate and amphetamines. These stimulants act by blocking the reuptake of norepinephrine and dopamine [31]. Methylphenidate, a psychostimulant, is the most commonly prescribed medication for children and adolescents with ADHD [32]. Its known side effects include abdominal pain, decreased appetite, headaches, and sleep disturbances [33–34]. Anxiety and depression have also been reported as frequent adverse effects of medications approved for the treatment of ADHD in children and adolescents [35]. Non-stimulant medications, such as atomoxetine, viloxazine, guanfacine, and clonidine, are recommended for patients who either do not respond to stimulant treatment or for whom there are concerns regarding potential misuse [31]. Methylphenidate and amphetamines have been found to be more effective than atomoxetine and guanfacine [6].

There is substantial evidence indicating that both stimulant and non-stimulant medications can significantly reduce symptoms of inattention and hyperactivity–impulsivity in school-aged children and older patients, with clinically meaningful improvements [36]. Recent reviews, meta-analyses, and clinical studies examining the long-term effects of ADHD medications in children and adolescents aged 6 to 18 years demonstrate that cognitive test scores and ADHD symptoms improve with well-controlled treatment over a one-year period. Additionally, the entire cohort showed a significant increase in Wechsler Full-Scale IQ (an average of 92.6 at baseline vs. 97.95 after

12 months). ADHD medications also substantially reduce the risk of mood disorders, criminal behavior, accidents, academic difficulties, and other adverse outcomes [33].

In a randomized, double-blind, placebo-controlled clinical trial published in 2024, Liang-Jen Wang et al. suggested that the probiotic supplement Bf-688 may enhance the neuropsychological functioning of children with ADHD by modulating gut microbiota. The 12-week trial involved children receiving a stable dose of methylphenidate (MPH). Results showed that supplementation with Bf-688 alleviated gastrointestinal side effects associated with MPH and promoted weight gain. Moreover, probiotic supplementation was associated with improvements in symptoms of inattention and hyperactivity [34].

Several studies report positive outcomes from iron supplementation as part of ADHD treatment in children [16,37]. In a 2022 study by Atcha Pongpitakdamrong et al., 116 children participated, 52 of whom were diagnosed with iron deficiency. Among the 52, half were assigned to the placebo group and half received iron supplementation. Significant improvements in ADHD symptoms were observed in children with ADHD and iron deficiency who also received methylphenidate [38].

Non-pharmacological treatment

Non-pharmacological approaches currently used for ADHD treatment include neuropsychological interventions and cognitive-behavioral therapy (CBT) [31]. Mindfulness-based techniques can serve as potential strategies to reduce impulsivity. Yoga, as a mindfulness practice, supports both physical and mental well-being and can provide meaningful therapeutic benefits. Evidence shows a strong association between yoga practice and improvement in ADHD symptoms [39].

Digital interventions also represent a promising non-pharmacological strategy to improve the mental and physical health of children with ADHD [40]. Digital therapies can enhance cognitive abilities, promote neuroplasticity, and modulate neuronal activity. Studies have demonstrated that video-based cognitive training can increase gray matter volume in the right hippocampus and right prefrontal cortex [2].

Music therapy represents another example of a non-pharmacological treatment. Several studies have shown that it can improve cognitive function and sensory-motor integration in individuals with ADHD. Music therapy can induce substantial physiological changes by stimulating the limbic system through auditory input, thereby eliciting therapeutic effects. The limbic system plays a central role in regulating heart rate, blood pressure, and respiration [41–44].

A 2017 study by Ferrán Catalá-López et al., analyzing 190 randomized trials involving 26,114 participants with ADHD, concluded that a combination of behavioral therapy and stimulant medication is more effective than either treatment alone. The combined approach demonstrated the best efficacy profile, while stimulant medications appeared more ben-

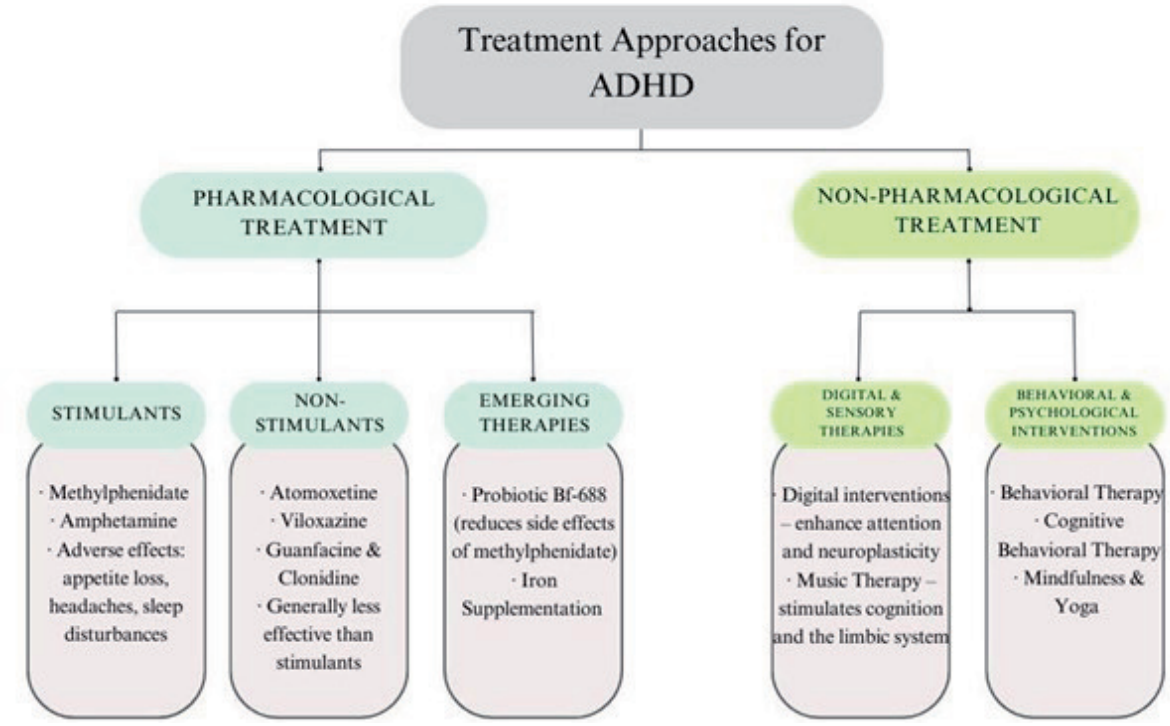

Figure 2. Comparative Overview of Pharmacological and Non-Pharmacological Treatment Approaches for ADHD [2,31-44]

eficial than behavioral therapy, cognitive training, or non-stimulant pharmacological treatments [6].

Conclusions

ADHD is a complex neurodevelopmental disorder that significantly affects the functioning of children and adolescents. A review of the literature underscores the importance of early diagnosis and a multifaceted therapeutic approach that includes pharmacological treatment, behavioral therapy, and environmental modifications.

Research findings highlight the effectiveness of combining pharmacotherapy with behavioral interventions to improve clinical outcomes. Additionally, certain supportive strategies, such as iron supplementation and probiotic therapy, may offer additional benefits for specific patient groups.

Modern diagnostic techniques, including EEG-based analyses and machine learning algorithms, show promise in improving the accuracy of ADHD identification. However, further research is necessary before these methods can be integrated into routine clinical practice. Currently, the standard diagnostic process remains grounded in DSM-5 criteria, supported by clinical evaluation and psychometric testing.

Future research should aim to deepen the understanding of the pathophysiological mechanisms underlying ADHD. This will facilitate the development of more personalized treatment strategies tailored to the individual needs and characteristics of patients.

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