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(REVIEW ARTICLE)

Ayurvedic approaches to neurodevelopmental disorders: Evidence, challenges and future directions

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Abstract

Neurodevelopmental disorders (NDDs) are the leading cause of long-term disability in children worldwide. They include autism spectrum disorder (ASD), attention-deficit/hyperactivity disorder (ADHD), cerebral palsy (CP), intellectual disability (ID), and specific learning disorders. Despite improvements in conventional management, many children still experience persistent cognitive, behavioral, motor and psychosocial impairments, highlighting the need for complementary therapeutic strategies. Ayurveda, especially the branch of *Kaumarabhritya*, offers a holistic approach in the management of pediatric neurological disorders by use of herbal medicines, dietary and lifestyle modifications and specialized therapeutic procedures. This narrative review assesses the current evidence, challenges, and future directions of Ayurvedic approaches for NDDs. A narrative review of the literature was done using PubMed, Google Scholar, and other available electronic databases along with classical Ayurvedic texts. Research indicates that *Medhya Rasayana* herbs (e.g., *Bacopa monnieri*, *Centella asiatica*, *Withania somnifera*, and *Tinospora cordifolia*) are antioxidants, anti-inflammatory, neuroprotective, adaptogenic, and neuroplasticity-enhancing, and cognitive and behavioral functions can be improved. Clinical studies have reported that Ayurvedic interventions, such as *Abhyanga, Nasya, Shirodhara* and selected Panchakarma procedures, have positive effects on attention, communication, motor function, adaptive behavior, sleep quality and overall quality of life when used in conjunction with conventional rehabilitation. However, evidence to date is limited by methodological challenges including small sample sizes, heterogeneity of intervention protocols, poor standardization, heterogeneous outcome measures and limited long-term follow-up. Future research should include multicentre randomized controlled trials, standardized formulations, validated outcome measures, biomarker-based investigations and mechanistic studies. Ayurveda seems to be a promising complementary aspect of multidisciplinary care in neurodevelopmental disorders, but strong clinical evidence is needed to support its evidence-based incorporation into pediatric practice.

Keywords: Ayurveda; Neurodevelopmental Disorders; *Medhya Rasayana*; Integrative Medicine

1. Introduction

Neurodevelopmental disorders (NDDs) constitute a broad spectrum of conditions characterized by deficits in cognitive, motor, language, behavioral, and social functioning that onset during the developmental period. The most common NDDs are autism spectrum disorder (ASD), attention-deficit/hyperactivity disorder (ADHD), intellectual disability, cerebral palsy, and specific learning disorders [1]. These conditions affect one in six children worldwide and constitute a significant public health challenge owing to their long-term impact on educational achievement, social participation, mental health and quality of life [2,3]. Recent advances in neuroscience have shown that NDDs are caused by complex

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interactions of genetic, epigenetic, environmental and neurobiological factors, resulting in a wide heterogeneity in clinical presentation and treatment response [4,2].

Management of NDDs is currently based on a multidisciplinary approach including behavioral therapy, speech and language therapy, occupational therapy, educational support and pharmacological treatment for symptom control. These interventions improve function, but many patients still have cognitive and behavioural problems, and drugs can have side effects. Hence, there has been increasing interest in complementary and integrative therapies that can be safely incorporated into conventional management [5,2].

Kaumarabhritya is a specialty of Ayurveda, the traditional Indian system of medicine, which considers child health from a holistic perspective. According to Ayurveda, normal neurodevelopment is dependent on the balanced functioning of *Dosha, Agni, Dhatu, Ojas* and *Manas*. Individualized therapeutic strategies include management of cognitive and behavioral disorders such as *Medhya Rasayana, Panchakarma, Abhyanga, Nasya, Shirodhara*, dietary regulation and lifestyle modification. Classical Ayurvedic texts describe these interventions as improving intellect (*Medha*), memory (*Smriti*), learning capacity and psychological well-being [6,7]. Pharmacological experimental studies have shown that some *Medhya Rasayana* plants, namely *Bacopa monnieri, Centella asiatica, Withania somnifera* and *Tinospora cordifolia* possess neuroprotective, antioxidant, anti-inflammatory, anxiolytic and cognition-enhancing activities. These mechanisms may play a role in improved synaptic plasticity, neurotransmitter regulation and neuronal survival, indicating potential therapeutic applications in neurodevelopmental disorders [8]. Moreover, recent systematic reviews have demonstrated promising evidence for Ayurvedic interventions in children with ADHD, but the certainty of this evidence is still limited due to methodological weaknesses, heterogeneous interventions and small sample sizes [9].

The growing global focus on evidence-based integrative medicine warrants a comprehensive evaluation of Ayurvedic interventions in neurodevelopmental disorders. The purpose of this review is to critically evaluate the current evidence of efficacy, safety and putative mechanisms of Ayurvedic therapies in the management of neurodevelopmental disorders, identify gaps in the existing research and suggest future directions for high-quality clinical and translational research.

Objectives

The study has the following objectives:

- To critically review the scientific evidence available on the efficacy and safety of Ayurvedic interventions in the management of neurodevelopmental disorders.
- To review Ayurvedic concepts, therapeutic interventions, and proposed mechanisms of action with respect to neurodevelopmental disorders.
- To identify gaps in existing research and propose future directions for high-quality research and integration of Ayurveda in evidence-based multidisciplinary care

2. Methodology

A narrative literature review was done in PubMed, Google Scholar, and other open electronic databases along with classical Ayurvedic texts. Relevant publications were reviewed and synthesized narratively to summarize the available evidence on the role of Ayurveda in the management of neurodevelopmental disorders.

3. Results and Discussion

A detailed review of the published literature revealed an increasing body of evidence for the possible role of Ayurvedic interventions in the management of neurodevelopmental disorders (NDDs). The evidence available included randomized controlled trials (RCTs), pilot clinical studies, observational studies, systematic reviews, meta-analyses, experimental investigations, and classical Ayurvedic literature. Most of the studies were published in the last decade, showing an increasing scientific interest in integrative approaches for paediatric neurological disorders [9,10].

The most studied conditions were autism spectrum disorder (ASD) and attention deficit/hyperactivity disorder (ADHD), followed by cerebral palsy (CP), intellectual disability (ID), and specific learning disorders. Most of the clinical trials have explored Ayurvedic therapies as an adjunct to conventional rehabilitation rather than as a stand-alone treatment [5,9].
The most studied interventions were *Medhya Rasayana* formulations, *Abhyanga* (therapeutic massage), *Shirodhara, Nasya, Panchakarma* procedures, *Svarna Prashana*, dietary modifications and lifestyle interventions. Among herbal

medicines, *Bacopa monnieri (Brahmi), Centella asiatica (Mandukaparni), Withania somnifera (Ashwagandha)* and *Tinospora cordifolia (Guduchi)* were consistently reported to have neuroprotective and cognition-enhancing properties [8,11,12].

In experimental studies, the medicinal plants were found to possess antioxidant, anti-inflammatory, anti-apoptotic, adaptogenic, and neuroprotective activities. Proposed mechanisms include altering cholinergic neurotransmission, reducing oxidative stress, increasing brain-derived neurotrophic factor (BDNF), regulating neurotransmitters, enhancing synaptic plasticity, and decreasing neuroinflammation. These biological mechanisms, therefore, provide a scientific rationale for the traditional Ayurvedic concept of *Medhya Rasayana* in augmenting cognitive development and neurological function [8,13].

Clinical trials on children with ADHD have shown that attention, concentration, impulsivity, hyperactivity, executive functioning, and academic performance improved with the administration of *Medhya Rasayana* formulations either alone or in combination with behavioral interventions. The studies on children with ASD also showed improvements in communication skills, social interaction, adaptive behavior, sleep quality, emotional regulation, and reduction in stereotypic behaviors with integration of Ayurvedic therapies with conventional rehabilitation [9,5].

Evidence for cerebral palsy suggested that integrative approaches based on *Abhyanga, Swedana, Basti,* and physiotherapy may improve muscle tone, gross motor function, balance, mobility, and activities of daily living. However, these results were mainly obtained from small clinical studies with heterogeneity of methodologies, highlighting the need for standardized intervention protocols and larger controlled studies [10].

Although reported results are promising, systematic reviews have consistently rated the certainty of evidence as low to moderate due to methodological limitations. The common limitations were poor randomization, lack of allocation concealment, lack of blinding, small sample size, nonstandardized formulation, treatment duration, different outcome measures, and limited long-term follow-up. Hence, current evidence supports Ayurveda as a complementary rather than an alternative therapeutic approach [9,14].

The literature review generally supports the potential role of Ayurvedic interventions in improving cognitive, behavioural, psychological and functional outcomes in children with neurodevelopmental disorders when used as part of multidisciplinary management. However, high-quality multicentre randomized controlled trials with standardized interventions, validated neurodevelopmental assessment tools and rigorous methodological designs are needed before routine clinical application [2,3].

Table 1 Clinical Evidence on Ayurvedic Interventions in Neurodevelopmental Disorders

Disorder	**Ayurvedic interventions**	**Reported outcomes**	**Overall evidence**
Autism Spectrum Disorder	*Medhya Rasayana, Abhyanga, Shirodhara, Nasya*	Improved communication, social interaction, adaptive behaviour, sleep quality, reduced stereotypic behaviour	Low–Moderate
ADHD	*Brahmi, Mandukaparni, Ashwagandha, Nasya, Panchakarma*	Improved attention, executive function, reduced hyperactivity and impulsivity	Moderate
Cerebral Palsy	*Abhyanga, Swedana, Basti* with physiotherapy	Improved motor function, muscle tone, mobility and quality of life	Low
Intellectual Disability	*Medhya Rasayana* formulations	Improved memory, learning ability and adaptive behaviour	Low
Learning Disorders	*Medhya Rasayana* and lifestyle interventions	Improved concentration and academic performance	Low

The findings indicate that autism spectrum disorder (ASD) and attention-deficit/hyperactivity disorder (ADHD) are the most researched conditions, with a relatively limited evidence base for cerebral palsy, intellectual disability and learning disorders. This trend suggests an increasing worldwide incidence of ASD and ADHD and a growing interest in complementary and integrative treatment approaches [3,2].

ADHD has the most clinical evidence of Ayurvedic interventions of the disorders reviewed. The strongest evidence is for the *Medhya Rasayana* herbs, *Bacopa monnieri (Brahmi), Centella asiatica (Mandukaparni)*, and *Withania somnifera (Ashwagandha).* Improvements in attention, executive functioning, hyperactivity, and impulsivity have been reported in clinical studies and systematic reviews, and antioxidant, neuroprotective, anti-inflammatory, and neurotransmitter-modulating properties have been demonstrated in experimental studies to support the biological plausibility of these clinical findings [8, 9].

Ayurvedic therapies like *Medhya Rasayana, Abhyanga, Shirodhara* and *Nasya* in conjunction with conventional rehabilitation have been reported to improve communication, social interaction, adaptive behaviour, quality of sleep and stereotypic behaviours in subjects with ASD. However, to date evidence remains low to moderate, with most of the published studies being pilot investigations with small sample sizes, heterogeneous treatment protocols and limited follow-up periods [5,9].

Evidence of Cerebral Palsy suggests *Abhyanga, Swedana* and *Basti,* especially with physiotherapy, may improve muscle tone, gross motor function, mobility and quality of life. Preliminary studies in children with intellectual disabilities and learning disorders also suggest that *Medhya Rasayana* formulations may be useful in improving memory, concentration, learning capacity and adaptive behaviour. However, these findings should be confirmed by randomized controlled trials with adequate sample size and standardized intervention protocols [10].

In summary, Table 1 shows promising adjunctive benefits of Ayurvedic interventions in various neurodevelopmental disorders. However, the existing evidence is marred by methodological limitations such as imperfect randomization, lack of allocation concealment, inadequate blinding, lack of standardized herb preparations, non-uniform outcome measures, and no long-term follow-up. In future multicentre randomized controlled trials, standardized Ayurvedic interventions, internationally validated neurodevelopmental assessment tools, and objective biomarkers will be required to establish efficacy, safety, and clinical applicability of Ayurveda in evidence-based pediatric neurodevelopmental care [2,9].

Table 2 Pharmacological Evidence of Common *Medhya Rasayana* Herbs

Herb	**Principal bioactive effects**	**Proposed neurological actions**	**Potential clinical relevance**
Bacopa monnieri	Antioxidant, neuroprotective	Enhances cholinergic activity, improves synaptic plasticity	Memory, attention, cognition
Centella asiatica	Antioxidant, neurogenic	Promotes neuronal regeneration and BDNF expression	Learning and cognitive enhancement
Withania somnifera	Adaptogenic, anti-inflammatory	Reduces oxidative stress and neuroinflammation	Behavioural regulation and cognition
Tinospora cordifolia	Immunomodulatory, antioxidant	Neuroprotection and anti-inflammatory activity	Cognitive support

Table 2 Pharmacological evidence for the use of commonly prescribed *Medhya Rasayana* herbs in neurodevelopment disorders (NDDs). These medicinal plants have several neurobiological effects which together may contribute to the enhancement of cognitive, behavioral and neurological functions. These pleiotropic effects are in line with the multifactorial pathophysiology of NDDs involving oxidative stress, neuroinflammation, mitochondrial dysfunction, neurotransmitter dysregulation, compromised synaptic plasticity and altered neurodevelopment [3,2].

The most studied *Medhya Rasayana* herb is *Bacopa monnieri (Brahmi),* which has demonstrated significant antioxidant and neuroprotective properties in experimental and clinical studies. The plant contains Bacosides A and B, major bioactives with therapeutic potential to improve cholinergic neurotransmission, synaptic plasticity, and neuronal communication that result in better memory, attention, learning, and information processing. Randomized controlled trials and systematic reviews in children and adults have reported positive cognitive performance effects, indicating that this may have a potential role in an adjunctive intervention for attention-deficit/hyperactivity disorder and other cognitive impairments [8,15].

Centella asiatica (Mandukaparni) has been shown to induce neuronal regeneration, dendritic arborization, and expression of brain-derived neurotrophic factor (BDNF), a key regulator of neurogenesis and synaptic plasticity. These

pharmacological properties can improve learning, memory, and executive function and protect neurons from oxidative damage. Experimental studies have also shown modulation of cholinergic and glutamatergic neurotransmission, further supporting its role in cognitive enhancement [11,16].

Withania somnifera (Ashwagandha) is well known for its potent adaptogenic, antioxidant, and anti-inflammatory activities. It has the potential to improve behavioral regulation, alleviate anxiety, and improve cognitive performance by reducing oxidative stress, suppressing pro-inflammatory cytokines, and modulating the hypothalamic-pituitary-adrenal (HPA) axis. These mechanisms are especially relevant to children with neurodevelopmental disorders in which chronic neuroinflammation and stress-related neuroendocrine dysregulation have been implicated in disease progression [17,2].

Tinospora cordifolia (Guduchi) has immunomodulatory, antioxidant, and anti-inflammatory properties that help in protecting neurons and maintaining cognitive functions. Pre-clinical data indicate that T. cordifolia reduces oxidative neuronal injury, inhibits inflammatory signaling pathways, and supports neuronal survival. But against *B. monnieri* and W. somnifera. The clinical evidence of efficacy of *W. somnifera* in neurodevelopmental disorders is limited, and well-designed human studies are needed [18,10].

In summary, the pharmacological data presented in Table 2 support the traditional Ayurvedic concept of *Medhya Rasayana* and demonstrate several biological mechanisms that may contribute positively to brain development, neuroplasticity and cognitive function. Despite a good preclinical basis, the number of high-quality randomized controlled trials is still low to translate these mechanisms into clinical practice. Future research should include standardized herbal formulations, dose-response relationships, pharmacokinetic and pharmacodynamic evaluations, long-term safety studies, and biomarker-based clinical studies to establish the efficacy and mechanisms of *Medhya Rasayana* herbs in evidence-based pediatric neurodevelopmental care.

Table 3 Proposed Mechanisms of Ayurvedic Interventions

Ayurvedic intervention	**Proposed biological mechanism**	**Potential therapeutic effect**
Medhya Rasayana (cognitive rejuvenative therapy)	Antioxidant, anti-inflammatory, neuroprotective, and cholinergic modulatory effects	Reduced oxidative stress and neuroinflammation with improved learning, memory, and attention
Abhyanga (therapeutic oil massage)	Sensory stimulation and autonomic nervous system regulation	Improved sleep quality, relaxation, and behavioural regulation
Shirodhara (continuous pouring of medicated liquid over the forehead)	Stress reduction and autonomic nervous system balance	Reduced anxiety and enhanced emotional regulation
Nasya (nasal administration of medicated preparations)	Potential modulation of central nervous system pathways through the nasal route	Improved cognitive and neurological functioning

Table 3 Proposed biological mechanisms of Ayurvedic interventions in management of neurodevelopmental disorders (NDDs). Unlike traditional treatments, which primarily address specific symptoms, Ayurvedic interventions appear to have multimodal effects, simultaneously influencing oxidative stress, neuroinflammation, neurotransmission, neuroplasticity, autonomic regulation, and neuroendocrine function. These different mechanisms are compatible with the multifactorial pathophysiology of NDDs and might explain the potential role of Ayurveda as a complementary therapeutic approach [3,2].

The *Medhya Rasayana* is the basis of Ayurvedic management of cognitive and behavioural disorders. Experimental studies have shown that *Medhya Rasayana* herbs have a strong antioxidant potential by scavenging reactive oxygen species, increasing the activity of endogenous antioxidant enzymes, and reducing lipid peroxidation. Oxidative stress has been implicated in the pathogenesis of autism spectrum disorder (ASD), attention-deficit/hyperactivity disorder (ADHD), and other NDDs, and thus, reduction of oxidative neuronal injury may improve cognitive and neurological functioning. Moreover, some *Medhya Rasayana* herbs have been reported to improve cholinergic neurotransmission by increasing the availability of acetylcholine and modulating cholinergic receptors, leading to improvements in attention, learning, memory, and executive functioning [8,12].

Neurophysiological mechanisms can also be ascribed to the effect of external Ayurvedic therapies on neurological functions. Continuous tactile stimulation via Abhyanga could improve sensory integration, regulation of the autonomic nervous system, peripheral circulation, and neuromuscular coordination. *Shirodhara* is also recommended to decrease sympathetic nervous system activity, improve parasympathetic dominance, and reduce physiological stress responses, which can lead to decreased anxiety, better emotional regulation, and improved quality of sleep [10].

Nasya involves the intranasal application of medicated oils or herbal formulations and is traditionally believed to have therapeutic effects on the head and central nervous system. In recent studies on intranasal drug delivery, it has been shown that drugs can be transported to the brain via the olfactory and trigeminal neural pathways. Part of this route bypasses the blood-brain barrier and permits rapid delivery of drugs to the central nervous system. While evidence for Ayurvedic Nasya formulations remains limited, this mechanism offers a plausible scientific rationale for the use of it in neurological disorders and may warrant further pharmacokinetic and clinical exploration [19,20].

Overall, the evidence summarized in Table 3 suggests that Ayurvedic interventions yield several complementary biological effects consistent with the current understanding of the pathophysiology of neurodevelopmental disorders. Most of the proposed mechanisms, however, have been demonstrated in experimental models and their clinical relevance remains to be determined. More translational research in molecular neuroscience, pharmacology, neuroimaging, biomarker analysis, and adequately powered randomized controlled trials are needed to confirm these mechanisms and to strengthen the evidence base for integrating Ayurveda into pediatric neurodevelopmental care [3, 2].

Table 4 Methodological Limitations of Current Studies

Limitation	**Potential impact**
Small sample sizes	Reduced statistical power
Heterogeneous treatment protocols	Limited comparability between studies
Lack of standardized herbal formulations	Poor reproducibility
Short intervention duration	Limited assessment of sustained efficacy
Inadequate randomization and blinding	Increased risk of bias
Variable outcome measures	Difficulty in evidence synthesis and meta-analysis

Table 4 summarizes the critical methodological limitations presently limiting the strength and clinical utility of evidence for Ayurvedic interventions for NDDs. Despite promising therapeutic results from several studies, the overall certainty of evidence remains low to moderate, owing to several recurrent methodological limitations observed in clinical trials and systematic reviews [9,10].

The most common limitations reported include small sample sizes, which reduce statistical power and increase the likelihood of both type I and type II errors. Many published clinical trials are pilot studies with <50 subjects, limiting the precision and generalizability of their findings to larger pediatric populations. Hence, appropriately powered multicentre randomized controlled trials are necessary to provide more reliable estimates of efficacy and safety of treatment [9,21].

Another limitation of inter-study comparisons is the high heterogeneity of treatment protocols. As the herbal formulations, dosage regimens, duration of therapy, Panchakarma procedures, and concurrent conventional rehabilitation varied, it was difficult to determine the efficacy of individual interventions. One of the central tenets of Ayurveda is individualization of treatment, which presents challenges to standardization in clinical research. Thus, development of consensus-based treatment protocols which are based on principles of Ayurveda and provide methodologically consistent treatment is important [10].

Another major drawback is the lack of standardization of herbal formulations and measures of quality control. Differences in botanical identification, growing conditions, harvesting practice, methods of extraction, and phytochemical composition may greatly influence therapeutic outcome and reduce reproducibility between studies. Therefore, standardization according to Good Manufacturing Practice (GMP) guidelines, pharmacognostic authentication, and phytochemical characterization are very important to improve the quality and reproducibility of future research [14,22].

Moreover, the majority of the available studies have relatively short intervention and follow-up periods, which limits the evaluation of long-term efficacy and safety of Ayurveda therapies. Neurodevelopmental disorders are chronic conditions that require long-term management, necessitating longer follow-up to assess the sustainability of clinical improvements, to monitor adverse events, and to evaluate long-term functional outcomes such as educational achievement, adaptive behaviour, and quality of life [3].

The risk of selection, performance, and detection bias is further increased by methodological weaknesses such as poor randomization, lack of allocation concealment, and lack of blinding of participants or assessors. Hence, the internal validity of the published studies is lowered. Future randomized controlled trials should adhere to internationally recognized standards for methodology and reporting such as the CONSORT Statement [23] and the CONSORT Extension for Herbal Medicinal Interventions [14] to improve transparency, reproducibility, and scientific rigor.

Finally, the use of heterogeneous and non-standardized outcome measures prevents evidence synthesis and the possibility of conducting high-quality meta-analyses. The instruments used in current studies to measure behaviour, cognition, function and quality of life vary widely, which makes direct comparison impossible. Future studies should utilize internationally validated neurodevelopmental assessment tools with objective biomarkers, neuroimaging results, and standardized reporting of clinical outcomes to enhance comparability between studies and strengthen the evidence base [21,2].

In conclusion, the constraints mentioned in Table 4 underline the need for higher methodological standards in Ayurvedic research. Well-designed multicentre randomized controlled trials with standardized interventions, appropriate sample sizes, longer follow-up periods, harmonized outcome measures and rigorous quality assurance procedures are crucial to strengthen the evidence base and facilitate the integration of Ayurveda into evidence-based multidisciplinary care for children with neurodevelopmental disorders.

Table 5 Research Priorities

Area	**Future recommendation**
Clinical research	Large multicentre randomized controlled trials
Standardization	Uniform Ayurvedic formulations and treatment protocols
Outcome assessment	Use validated neurodevelopmental scales and biomarkers
Mechanistic research	Neuroimaging, genomics, metabolomics and gut–brain axis studies
Long-term evaluation	Extended follow-up for safety and effectiveness
Integrative medicine	Develop multidisciplinary treatment models combining Ayurveda with conventional rehabilitation

Table 5 presents the major research priorities for building a stronger evidence base for Ayurvedic interventions in neurodevelopmental disorders (NDDs). Current research indicates potential therapeutic value, but future investigations need to adhere to rigorous scientific standards and globally accepted reporting guidelines to allow for the incorporation of Ayurvedic therapies into evidence-based clinical practice [22,21].

The most important step is to conduct large, multicentre, adequately powered randomized controlled trials. Most published studies suffer from small sample sizes, single-centre recruitment and methodological heterogeneity, limiting the precision and generalizability of the findings. Collaborative multicentre studies involving paediatric neurologists, psychiatrists, developmental paediatricians, rehabilitation specialists, biostatisticians and ayurvedic physicians could provide more robust evidence regarding efficacy, safety and cost-effectiveness of ayurvedic interventions and also increase the external validity [9, 2].

Standardization of Ayurvedic formulations and treatment protocols is another important area of research. The heterogeneity between studies and poor reproducibility is mainly due to heterogeneity in herbal composition, dose and duration of treatment, Panchakarma procedures, and individualization of the therapeutic approaches. Standardized preparations following Good Manufacturing Practice (GMP) guidelines, pharmacognostic authentication, phytochemical characterization, and strict quality assurance procedures should be used in future studies to ensure consistency in clinical trials [14,22].

The assessment of outcomes should include more than traditional clinical observation and should extend to the use of internationally validated neurodevelopmental assessment tools and objective biological markers. Biomarkers of oxidative stress, inflammation, neuroplasticity, and neurodevelopment should be added to standardized measures of cognition, executive function, adaptive behavior, language development, social functioning, and quality of life. This kind of multidimensional assessment would not only increase the reliability of outcome evaluation but also give insights into the biological mechanisms underlying therapeutic responses [3,2].

Mechanistic research is another important priority. Recent advances in neuroscience provide opportunities to study the biological effects of Ayurvedic interventions using structural and functional neuroimaging, genomics, transcriptomics, proteomics, metabolomics and gut–brain axis analyses. This combination of technologies with pharmacological and clinical studies can further aid in the elucidation of the molecular and physiological pathways by which *Medhya Rasayana* herbs and *Panchakarma* therapies influence brain development, synaptic plasticity, neuroinflammation and cognitive functions [24,13].

Neurodevelopmental disorders are lifelong disorders, so Ayurvedic interventions need to be evaluated on a long-term basis. Long-term follow-up studies are recommended to assess the durability of the therapeutic benefits, long-term safety, functional independence, educational achievement, social participation and health-related quality of life. Such longitudinal data are required to establish whether early Ayurvedic interventions offer continued developmental benefits through childhood and adolescence [3].

Finally, future research should focus on developing integrative models of care by combining evidence-based Ayurvedic interventions with conventional rehabilitation, behavioral therapy, occupational therapy, speech and language therapy, educational interventions and family-centered support. These multidisciplinary approaches are likely to optimize functional outcomes and to meet the complex bio-psycho-social needs of children with neurodevelopmental disorders. Establishment of collaborative national and international research networks, harmonized clinical protocols and standardized reporting frameworks will be vital in generating high-quality evidence and promoting integration of Ayurveda into mainstream pediatric neurodevelopmental care [22,5].

4. Conclusion

Neurodevelopmental disorders (NDDs) are an important global public health issue and require comprehensive, multidisciplinary, and individualized management strategies. The existing evidence suggests that Ayurveda, in particular the principles of *Kaumarabhritya* and interventions like *Medhya Rasayana, Abhyanga, Nasya, Shirodhara* and *Panchakarma*, may have useful adjunctive therapeutic benefits in improving cognitive, behavioral, motor and adaptive functioning in children with NDDs. Experimental studies have shown the neuroprotective, antioxidant, anti-inflammatory, immunomodulatory and neuroplasticity-enhancing effects of several Ayurvedic medicinal plants. Clinical studies have reported improvement in attention, memory, executive function, communication, social interaction, sleep quality, adaptive behavior and quality of life in the intervention group in addition to conventional rehabilitation.

However, these encouraging results are counterbalanced by the overall low certainty of evidence due to methodological limitations such as small sample sizes, heterogeneous treatment protocols, inadequate randomization and blinding, lack of standardized herbal formulations, inconsistent outcome measures and short follow-up periods. Thus, the current available evidence supports the use of Ayurveda as an adjunct therapy and not a substitute therapy for neurodevelopmental disorders. Its most promising avenue at present is its combination with evidence-based conventional rehabilitation in multidisciplinary models of pediatric care.

Future studies should focus on well-designed multicenter randomized controlled trials, standardized interventions of Ayurveda, validated neurodevelopmental assessment tools, biomarker-based outcome measures, and mechanistic studies incorporating advances in neuroscience, neuroimaging, genomics, metabolomics, and gut-brain axis research. Collaborative translational research among the Ayurvedic physicians, paediatric neurologists, developmental paediatricians, rehabilitation specialists, neuroscientists, and pharmacologists will be essential for high-quality evidence generation. Rigorous clinical and mechanistic research can enhance the scientific basis of Ayurveda, facilitating its safe, effective, and evidence-based integration into multidisciplinary pediatric neurodevelopmental care, and finally improving functional outcomes, quality of life, and long-term developmental trajectories of children with neurodevelopmental disorders.

Compliance with ethical standards

Disclosure of conflict of interest

The authors declare that they have no financial or non-financial conflicts of interest related to this work.

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