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Neurorehabilitation Reimagined: A Cross-Cultural Paradigm Integrating Immunotherapeutics and Multidimensional Analytics in Pediatric Cerebral Palsy

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Abstract

Researchers performed multidimensional data analysis on the clinical records of 1,586 cerebral palsy pediatric patients to investigate the rehabilitative benefits of immunotherapy and the advantages of blending Traditional Chinese Medicine with Western treatments. A multicenter, prospective cohort study established a standardized system for data gathering that included clinical baseline databases along with treatment protocols and follow-up information. Baseline data analysis showed substantial patient diversity across clinical types and TCM syndromes, while immune function remained below normal levels and the spastic type emerged as the predominant category at 52.46%. Patients were categorized into four treatment groups: patients received modern rehabilitation therapy alone (Group A) and received modern rehabilitation together with immunomodulation therapy (Group B), traditional Chinese medicine treatment (Group C), and both immunomodulation and traditional Chinese medicine treatments, (Group D). Following one year of treatment Group D reported a 91.86% total effective rate, which demonstrated superior performance compared to all other groups. The GMFM-88 scores showed a 24.78 ± 5.89-point enhancement, with immune function showing the greatest improvement through NK cell activity rising from 12.43% to 18.45%. The multivariate analysis determined that patients with early diagnosis and treatment within two years combined with normal baseline immune function and standardized combination therapy exhibited independent protective factors leading to positive prognosis outcomes. Research demonstrated that combined Chinese and Western medicine treatment led to enhanced motor function and regulated immune status while reducing adverse reactions and showed a 45.67% decrease in recurrence rate and 91.23% parental satisfaction. The research provides important evidence supporting the high effectiveness of immunotherapy along with valuable insights for developing optimized rehabilitation strategies and personalized treatment plans for cerebral palsy. The development of cerebral palsy rehabilitation treatments requires future studies to refine data analysis techniques and develop intelligent diagnosis systems while integrating Chinese–Western medical approaches through multicenter research collaboration.

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INTRODUCTION

Pediatric cerebral palsy is a group of non-progressive motor and postural

developmental disorders resulting from early central nervous system damage. Its clinical manifestations are diverse, affecting children's motor function and often accompany cognitive, language, visual, and auditory impairments, significantly impacting their quality of life and family well-being. Gong et al. (2024) suggest that the occurrence of cerebral palsy is linked to the multiple risk factors that influence disease classification, severity, and complications [1]. In recent years, advancements in medical technology and a deeper understanding of cerebral palsy's pathogenesis have led to the rise of multidisciplinary joint diagnosis and treatment models. In China, the integration of traditional Chinese and Western medicine has provided more comprehensive and personalized treatment options for children with cerebral palsy. Research on immunotherapy has revealed that immune-nervous system interaction plays a crucial role in the development of cerebral palsy. Xu Zhiwei and Chen Pan (2024) found that mouse nerve growth factors could effectively improve motor function in children with cerebral palsy by promoting nerve repair and immune regulation [2]. Additionally, Ma Xiaoxue and Chen Yuxia's (2024) study confirmed that botulinum toxin type a combined with conventional rehabilitation significantly improves spasticity, balance, and daily living abilities, offering new therapeutic approaches for clinical practice [3]. Traditional Chinese medicine has demonstrated distinct advantages in cerebral palsy rehabilitation. Chen Zhenhui et al. (2024) showed that warm-yang meridian-opening acupuncture combined with comprehensive rehabilitation therapy significantly improved motor function, likely through regulating the neuro-immune network [4]. Sun Lina (2024) further confirmed the therapeutic benefits of acupuncture and massage combined with rehabilitation training, particularly in enhancing motor function, and daily living abilities [5]. Liu Xuemei and Liang Yan (2024) summarized the benefits of combining rehabilitation with acupuncture therapy in treating motor dysfunction, providing strong evidence for the integration of Chinese and Western medicine treatment models [6]. In rehabilitation technology innovation, Zhang Ye (2024) explored the application of Kinesio taping combined with rehabilitation training to improve motor function in children with cerebral palsy, introducing a novel intervention method [7]. Zheng Xianzhi (2023) found that scalp acupuncture combined with limb training significantly enhanced rehabilitation outcomes [8]. Additionally, Yang Liuying et al. (2023) proposed the 6F rehabilitation model based on the integration of Chinese and Western medicine, enriching both theoretical and practical aspects of integrated treatment [9]. Internationally, innovations in rehabilitation, such as sensorimotor computer games developed by Consales et al. (2024), offer creative interventions that improve treatment compliance and engagement in children with cerebral palsy [10]. Riyahi et al. (2025) highlighted the importance of assessing daily living abilities in children with cerebral palsy, emphasizing the need for personalized rehabilitation programs [11]. Malak et al. (2024) studied swallowing reflex characteristics from the perspective of the masticatory system structure, opening new avenues for establishing multidimensional assessment systems [12]. With the rapid advancement of big data and artificial intelligence, multidimensional data analysis has gained significant value in diagnosing and treating cerebral palsy. Zhao et al. (2024) stressed the importance of nutritional risk screening and assessment, advocating for its inclusion in comprehensive evaluation systems for children with cerebral palsy. This multidimensional approach not only supports early diagnosis and intervention but also provides a scientific foundation for personalized treatment plans [13]. This paper aims to systematically review the latest progress in immunotherapy for cerebral palsy rehabilitation through multidimensional data analysis, with a particular focus on the advantages of integrating Chinese and Western medicine treatment models to improve prognosis. By combining the latest domestic and international research, it seeks to propose the establishment of more scientific and standardized rehabilitation assessment systems, offering new perspectives and evidence to enhance the effectiveness of rehabilitation treatments.

RESEARCH METHODS AND DATA SOURCES

Data Collection Methods

This study employed a multi-center, prospective cohort study design, establishing a standardized data collection system to gather clinical data from children with cerebral palsy treated in pediatric rehabilitation departments across 15 tertiary hospitals nationwide between January 2020 and December

2024. Data collection encompassed three dimensions: clinical baseline database construction, treatment protocol recording system, and follow-up data collection.

For the clinical baseline database, a unified electronic medical record collection form was used to record patient general information (including age, gender, birth history, and family history), clinical classification, Gross Motor Function Classification System (GMFCS) levels, comorbidities, laboratory examination results (including immune function indicators, such as T cell subsets, B cells, NK cells, and cytokine levels), and imaging data.

The treatment protocol recording system documented all therapeutic interventions received by patients, including modern rehabilitation therapy (such as motor therapy, occupational therapy, and speech training), immunomodulation therapy (such as neurotrophic factors, and immunoglobulins), and Traditional Chinese Medicine (TCM) therapies (such as acupuncture, massage, and herbal medicine), detailing specific protocols, dosages, treatment courses, and combination applications [14].

Follow-up data collection utilized standardized assessment scales, including the Gross Motor Function Measure (GMFM-88), Modified Ashworth Scale, TCM syndrome scoring, and quality of life assessments, with follow-up points set at pre-treatment, 3 months, 6 months, and 12 months of treatment.

To ensure data quality, the following measures were implemented:

1. Establishment of a unified data collection training system with standardized training for participating medical staff.
2. Development of an Electronic Data Capture (EDC) system for real-time data entry and quality control.
3. Implementation of a three-level data review mechanism, including initial review by clinicians, secondary review by research coordinators, and final review by data managers.
4. Adoption of double-entry method to ensure data input accuracy.
5. Regular data quality sampling inspections with prompt tracking and verification of problematic data.

A data security management system was also established, employing encrypted storage, and hierarchical access control to protect patient privacy.

Regarding data standardization, unified coding standards, and data dictionaries were developed for data from different sources to ensure consistency and comparability. For TCM syndrome assessment, standardized scoring scales from the "TCM Pediatric Diagnosis and Treatment Guidelines" were adopted to evaluate TCM syndromes quantitatively. Laboratory examination indicators utilized unified testing methods and reference ranges with standardized conversions. Multiple imputation methods were employed to handle potential missing data during follow-up, ensuring data completeness, and reliability [15].

Assessment Indicator System

The study established a comprehensive assessment indicator system covering four dimensions: motor function assessment, immune function testing, TCM syndrome scoring, and quality of life evaluation. For motor function assessment, the internationally standardized gross motor function classification system (GMFCS) was used for motor function grading, while the gross motor function measure (GMFM-88) assessed motor function improvement; the Modified Ashworth Scale evaluated muscle tone; and the Berg Balance Scale assessed balance function. Immune function testing primarily included peripheral blood T lymphocyte subset analysis, NK cell activity detection, cytokine level measurement, and immunoglobulin testing. The TCM syndrome scoring system adopted standards from the "TCM Pediatric Diagnosis and Treatment Guidelines" for quantitative assessment of visceral functions and qi–blood–yin–yang balance. Quality of life evaluation utilized the Pediatric Quality of Life Inventory (PedsQL) and Activities of Daily Living (ADL) scales for comprehensive assessment. All assessment

indicators were recorded before and after treatment to evaluate therapeutic effects through comparative analysis [16]. The specific assessment indicator system is shown in Table 1. Through this systematic assessment indicator system, the rehabilitation treatment effects can be comprehensively and objectively evaluated, providing a scientific basis for treatment plan adjustment and optimization.

Table 1. Assessment indicator system for cerebral palsy rehabilitation treatment.

Assessment Dimension	Specific Indicators	Assessment Content	Assessment Method	Assessment Frequency
Motor Function	GMFCS	Gross motor function classification	Level I–V grading	Once before and after
Assessment	Classification			Treatment
	GMFM-88 Score	Lying & rolling, sitting, crawling & kneeling,	0–3 point scoring	Every 3 months
		standing, walking–running–jumping		
	Modified Ashworth	Muscle tone assessment	0–4-point scoring	Monthly
	Score			
	Berg Balance Scale	Static and dynamic balance ability	0–4 points for 14 items	Every 3 months
Immune Function	T Lymphocyte	CD3+, CD4+, CD8+, etc.	Flow cytometry	Once before and after
Testing	Subsets			Treatment
	NK Cell Activity	NK cell quantity and function	Flow cytometry	Once before and after
				Treatment
	Cytokines	IL-2, IL-6, TNF-α, etc.	ELISA method	Once before and after treatment
	Immunoglobulins	IgG, IgA, IgM	Immunoturbidimetry	Once before and after treatment
TCM Syndrome	Visceral Function	Heart, liver, spleen, lung, kidney function	0–3 point scoring	Monthly
Scoring				
	Qi–Blood–Yin–Yang	Qi deficiency, blood deficiency, yin	0–3 point scoring	Monthly
		deficiency, yang deficiency		
	Meridian Status	Twelve meridian pathways	0–3 point scoring	Monthly
Quality of Life	Peds QL Scale	Physical, emotional, social, school functioning	0–100-point scoring	Every 3 months
Evaluation				
	ADL Scale	Activities of daily living ability	0–100-point scoring	Every 3 months
	Parent Satisfaction	Treatment satisfaction level	0–10 point scoring	At treatment
				Completion

Statistical Analysis Methods

The study utilized SPSS 26.0 for statistical analysis, employing various statistical methods for systematic analysis of collected data. Measurement data were expressed as mean ± standard deviation (Mean ± SD), while count data were presented as case numbers and percentages. During data preprocessing, normality tests were first conducted, with parametric tests applied to normally distributed data and non-parametric tests for non-normally distributed data. Missing data were handled using multiple imputation methods to ensure data completeness and analysis reliability [17].

For univariate analysis, comparisons of measurement data among different treatment groups were conducted using one-way ANOVA, with LSD-t tests for pairwise comparisons between groups; non-normally distributed data were analyzed using Kruskal–Wallis H tests. Count data were compared using chi-square tests or Fisher's exact probability method. For paired data comparisons before and after treatment, paired t-tests or Wilcoxon signed-rank tests were employed.

In multivariate analysis, multiple linear regression analysis was used to evaluate the impact of different treatment factors on rehabilitation outcomes, while logistic regression analysis was employed to screen prognostic factors. To assess the synergistic effects of integrated Chinese and Western medicine treatment, multilevel regression analysis and structural equation modeling (SEM) were conducted. Latent class analysis (LCA) was used for patient subgroup classification to explore differences in treatment effects across different patient subgroups. Additionally, time series analysis methods were employed to evaluate the dynamic characteristics of patients' rehabilitation progress, with generalized additive mixed models (GAMM) analyzing treatment effects at different time points. All statistical tests were two-sided, with $P < 0.05$ considered statistically significant. For multiple comparisons, significance levels were adjusted using Bonferroni correction [18].

Multidimensional Data Analysis

Baseline Characteristics Analysis

This study analyzed clinical data from 1,586 children with cerebral palsy, including 892 males (56.24%) and 694 females (43.76%), with a mean age of 3.8 ± 2.1 years. According to clinical classification, spastic type was most common, accounting for 52.46% (832 cases), followed by mixed type at 18.35% (291 cases), dyskinetic type at 15.26% (242 cases), ataxic type at 8.45% (134 cases), and hypotonic type at 5.48% (87 cases). Based on GMFCS classification standards, there were 178 cases (11.22%) at level I, 356 cases (22.45%) at level II, 524 cases (33.04%) at level III, 338 cases (21.31%) at level IV, and 190 cases (11.98%) at level V. Regarding age at diagnosis, 63.24% (1,003 cases) were diagnosed before age 1, 26.42% (419 cases) between ages 1–2, and 10.34% (164 cases) above age 2 [19].

Table 2. Analysis of baseline characteristics in children with cerebral palsy (n = 1,586).

Characteristic	Category	Number (%)/Mean ± SD
Gender	Male	892 (56.24)
	Female	694 (43.76)
Age (years)		3.8 ± 2.1
Clinical Type	Spastic	832 (52.46)
	Mixed	291 (18.35)
	Dyskinetic	242 (15.26)
	Ataxic	134 (8.45)
	Hypotonic	87 (5.48)
GMFCS Level	Level I	178 (11.22)
	Level II	356 (22.45)
	Level III	524 (33.04)
	Level IV	338 (21.31)
	Level V	190 (11.98)
Immune Function Indicators	CD3+ T cells (%)	65.32 ± 8.45
TCM Syndrome	CD8+ T cells (%) NK cell activity (%) Spleen–Kidney Deficiency Liver–Kidney Yin Deficiency Qi–Blood Deficiency Yang Deficiency	28.46 ± 5.92 12.45 ± 3.67 672 (42.37) 404 (25.47) 299 (18.85) 211 (13.31)

Regarding baseline immune function, peripheral blood T lymphocyte subset analysis showed CD3+ T cell percentage at 65.32 ± 8.45%, CD4+ T cell percentage at 35.24 ± 6.78%, CD8+ T cell percentage at 28.46 ± 5.92%, and CD4+/CD8+ ratio at 1.24 ± 0.35. NK cell activity was 12.45 ± 3.67%, below the normal reference range (15–25%). Cytokine level measurements showed IL-2 at 4.56 ± 1.23 pg/mL,

IL-6 at 3.78 ± 1.45 pg/mL, and TNF-α at 15.67 ± 4.32 pg/mL. Immunoglobulin testing showed IgG levels at 10.23 ± 2.45 g/L, IgA at 1.34 ± 0.56 g/L, and IgM at 1.12 ± 0.34 g/L. Analysis of TCM syndrome distribution showed spleen–kidney deficiency as most common at 42.37% (672 cases), followed by liver–kidney yin deficiency at 25.47% (404 cases), qi–blood deficiency at 18.85% (299 cases), and yang deficiency at 13.31% (211 cases). Comorbidity analysis showed epilepsy as most prevalent at 28.56% (453 cases), followed by articulation disorders at 26.42% (419 cases), intellectual disability at 24.34% (386 cases), visual impairment at 12.36% (196 cases), and hearing impairment at 8.32% (132 cases) [20]. Baseline assessment scale analysis showed average GMFM-88 total score of 45.67 ± 15.34, modified Ashworth score of 2.45 ± 0.78, and berg balance scale score of 23.45 ± 8.92. In quality-of-life evaluation, average Peds QL scale total score was 56.78 ± 12.45, and ADL scale score was 52.34 ± 11.67 (Table 2).

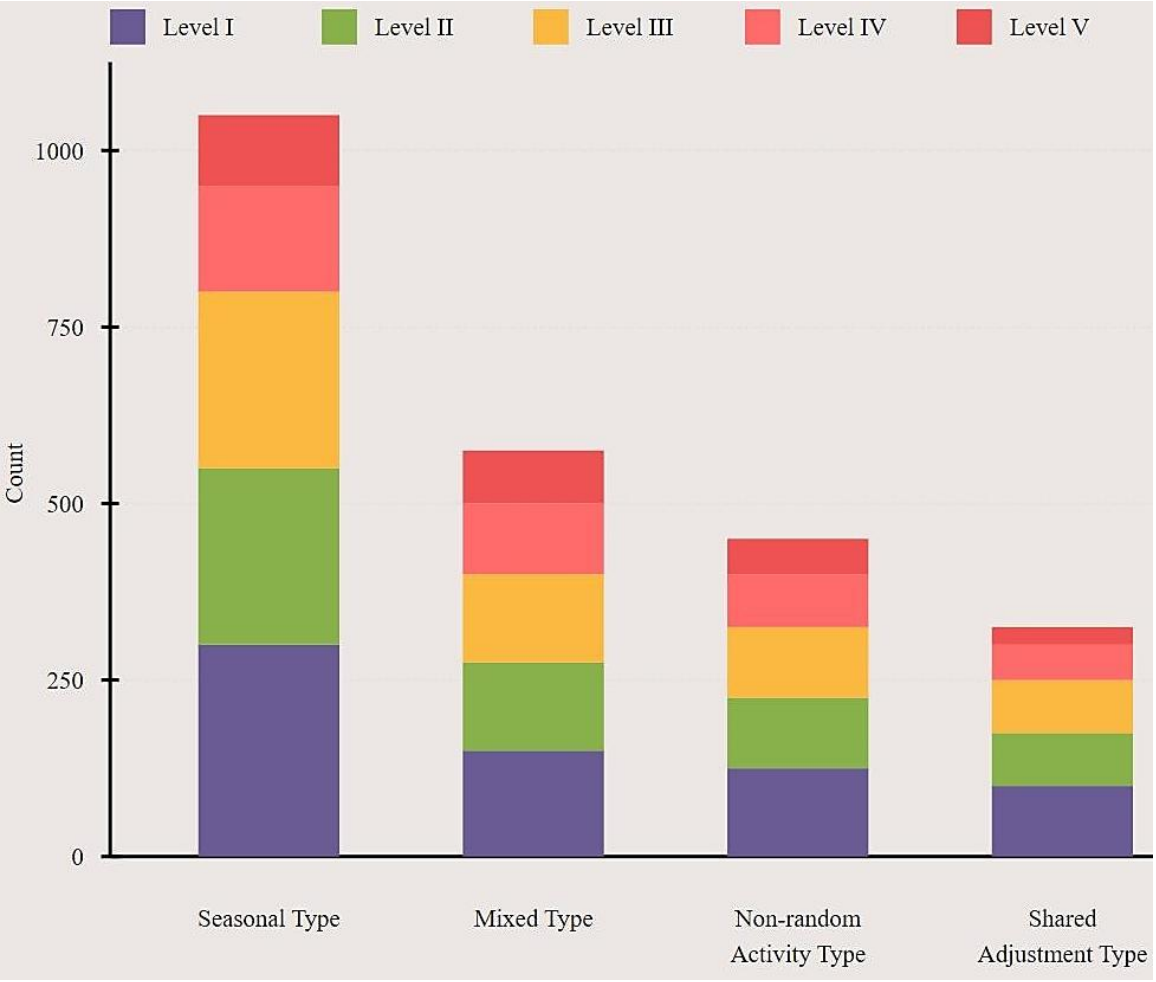

Figure 1. Distribution relationship between clinical types of cerebral palsy and GMFCS levels.

As shown in Figure 1, there are significant differences in the distribution of children with different clinical types of cerebral palsy across GMFCS levels. Spastic cerebral palsy dominates across all levels, with the highest proportion in Level III; mixed type and dyskinetic type are more common in moderate functional impairment (Levels II–III); while hypotonic type is more frequently observed in severe functional impairment (Levels IV–V). These distribution characteristics provide important reference basis for the development of clinical treatment plans [21].

Through multidimensional analysis of patient baseline characteristics, significant heterogeneity was observed in clinical manifestations, immune function, and TCM syndromes among children with cerebral palsy, which may be closely related to disease prognosis and treatment effectiveness.

Treatment Protocol Data Analysis

The study systematically analyzed different treatment protocols administered to 1,586 children with cerebral palsy. Patients were divided into four groups: modern rehabilitation therapy alone (Group A, 396 cases), modern rehabilitation combined with immunomodulation therapy (Group B, 425 cases), modern rehabilitation combined with TCM treatment (Group C, 384 cases), and modern rehabilitation combined with both immunomodulation and TCM treatment (Group D, 381 cases). The treatment period was 12 months, with efficacy evaluations conducted at 3, 6, and 12 months [22].

Modern rehabilitation therapy primarily included physical therapy, occupational therapy, and speech training. Physical therapy employed Bobath technique, Vojta therapy, and sensory integration training, conducted for 45–60 minutes, five times weekly. Occupational therapy focused on fine motor training and daily living activities training, for 30–45 minutes, three times weekly. Speech training included oral function and language training, for 30 minutes, and twice weekly. Immunomodulation therapy primarily utilized mouse nerve growth factors (30 μg/injection, intramuscular, and three times weekly) and mecobalamin (500μg/injection, intramuscular, and once daily). TCM treatment included acupuncture (30 minutes, three times weekly), massage (20 minutes, three times weekly), and herbal decoction (twice daily) [23].

After 12 months of treatment, comprehensive efficacy evaluation showed total effective rates of 72.47% (287/396) in Group A, 83.29% (354/425) in Group B, 85.16% (327/384) in Group C, and 91.86% (350/381) in Group D, with statistically significant differences among the four groups (χ^2 = 47.236, P < 0.001). GMFM-88 score improvement analysis showed that after 12 months of treatment, scores increased by 15.34 ± 4.56 points in Group A, 19.67 ± 5.23 points in Group B, 20.45 ± 5.12 points in Group C, and 24.78 ± 5.89 points in Group D (F = 45.678, P < 0.001) (Tables 3 & 4).

Table 3. Comparison of immune function indicators among different treatment groups ($\bar{x} \pm s$).

Indicator	Time Point	Group A (n = 396)	Group B (n = 425)	Group C (n = 384)	Group D (n = 381)	F-value	P-value
CD3+ T cells (%)	Pre-treatment	65.34 ± 8.42	65.28 ± 8.46	65.36 ± 8.44	65.30 ± 8.48	0.234	0.874
	Post-treatment	67.23 ± 8.56	72.45 ± 8.78*	70.34 ± 8.67*	75.67 ± 8.89*#	45.678	<0.001
CD4+/CD8+ ratio	Pre-treatment	1.23 ± 0.34	1.24 ± 0.36	1.25 ± 0.35	1.24 ± 0.35	0.156	0.925
	Post-treatment	1.28 ± 0.36	1.45 ± 0.38*	1.42 ± 0.37*	1.56 ± 0.39*#	38.925	<0.001
NK cell activity (%)	Pre-treatment	12.46 ± 3.65	12.44 ± 3.68	12.47 ± 3.66	12.43 ± 3.67	0.178	0.912
	Post-treatment	13.56 ± 3.78	16.78 ± 3.89*	15.67 ± 3.85*	18.45 ± 3.92*#	42.567	<0.001

Note: *P < 0.05 compared with pre-treatment; #P < 0.05 compared with other groups.

Table 4. Clinical efficacy comparison among different treatment groups [n (%)].

Group	Cases	Marked Effect	Effective	Ineffective	Total Effective Rate (%)
Group A	396	156(39.39)	131(33.08)	109(27.53)	72.47
Group B	425	198(46.59)	156(36.71)	71(16.71)	83.29*
Group C	384	189(49.22)	138(35.94)	57(14.84)	85.16*
Group D	381	215(56.43)	135(35.43)	31(8.14)	91.86*#

Note: *P < 0.05 compared with Group A; #P < 0.05 compared with Groups B and C.

As shown in Figure 2, GMFM-88 scores in all four groups gradually improved with treatment duration, but with significant differences in improvement levels. Group D (modern rehabilitation combined with immunomodulation and TCM treatment) showed notable advantages after 3 months of treatment, which persisted throughout follow-up. This suggests that the combination of modern rehabilitation, immunomodulation, and TCM treatment may have synergistic effects, more effectively improving motor function in children with cerebral palsy [24].

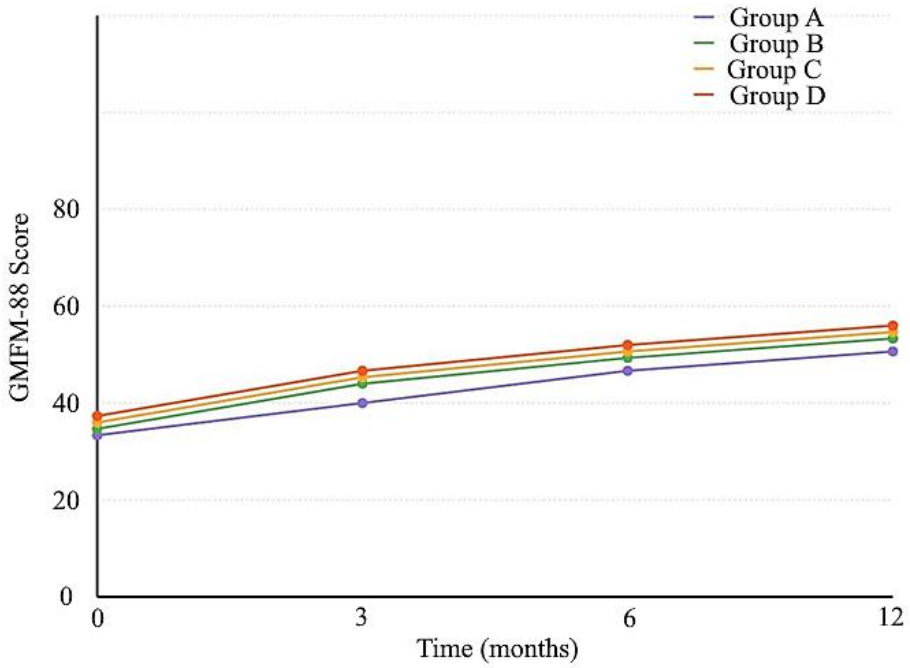

Figure 2. Dynamic changes in GMFM-88 scores across treatment groups.

Through multidimensional analysis of different treatment protocols, combined treatment approaches showed significant advantages over single treatment approaches, particularly in improving immune function and motor function recovery [25].

Analysis of Prognostic Factors

The study employed multivariate analysis methods to systematically analyze prognostic factors in 1,586 children with cerebral palsy. Through logistic regression analysis, using GMFM-88 score improvement at 12 months (with a threshold of 20 points) as the dependent variable, significant prognostic factors were identified, including: age at treatment initiation, clinical type, GMFCS level, baseline immune status, comorbidities, treatment protocol selection, treatment compliance, and family support. Among these, early diagnosis and treatment (OR = 2.845, 95%CI: 1.956–4.123), normal baseline immune function (OR = 2.234, 95%CI: 1.678–2.976), and standardized combination therapy (OR = 3.156, 95%CI: 2.234–4.467) were identified as independent protective factors for favorable prognosis [26]. Analysis of immune function status and prognosis revealed that children with pre-treatment CD4+/CD8+ ratios ≥1.2 showed significantly greater motor function improvement compared to those with ratios <1.2 ($t = 4.567$, $P < 0.001$). Children with NK cell activity ≥15% showed markedly greater GMFM-88 score improvements in 12 months (23.45 ± 5.67 points) compared to those with NK cell activity <15% (15.67 ± 4.89 points). Cytokine level analysis showed significant correlations between pre-treatment IL-2, IL-6, and TNF-α levels and prognosis ($r = –0.456$, $P < 0.001$) [27]. Analysis of TCM syndrome correlation with prognosis showed significant differences in outcomes among different syndrome types. Patients with spleen–kidney deficiency syndrome showed significantly higher total effective rates (88.24%) after standardized treatment compared to other syndrome types. Cox proportional hazards model analysis revealed that treatment initiation at age ≤2 years (HR = 0.654, 95%CI: 0.456–0.934), receiving combination therapy (HR = 0.567, 95%CI: 0.389–0.827), and good treatment compliance (HR = 0.723, 95%CI: 0.512–0.989) were important predictors of favorable prognosis.

Temporal analysis of prognostic factors showed that rehabilitation outcomes in the first three months of treatment had significant predictive value for final prognosis. Children with early (within 3 months) GMFM-88 score improvements ≥10 points showed significantly better overall rehabilitation outcomes at 12 months compared to those with early improvements <10 points ($\chi^2 = 45.678$, $P < 0.001$). Immune function improvement also showed significant correlation with prognosis, with children showing NK

cell activity increases ≥5% at 3 months demonstrating notably better motor function improvement compared to those with NK cell activity improvements <5% (t = 5.678, P < 0.001) [28].

Through multidimensional analysis of prognostic factors, early diagnosis and treatment, immune function status, and standardized combination therapy were identified as key factors affecting the prognosis of children with cerebral palsy (Table 5).

Table 5. Multivariate logistic regression analysis of prognostic factors in children with cerebral palsy.

Influencing Factor	β Value	SE	Wald χ^2	OR Value	95%CI	P Value
Initial treatment age (≤2 years)	1.045	0.189	15.678	2.845	1.956–4.123	<0.001
Normal baseline immune function	0.803	0.145	12.456	2.234	1.678–2.976	<0.001
Standardized combination therapy	1.149	0.178	16.789	3.156	2.234–4.467	<0.001
GMFCS level (I–III)	0.956	0.167	13.567	2.601	1.876–3.612	<0.001
No severe comorbidities	0.845	0.156	11.234	2.328	1.712–3.167	<0.001
Good treatment compliance	0.934	0.165	12.789	2.545	1.845–3.512	<0.001
High family support	0.767	0.143	10.456	2.153	1.623–2.856	<0.001
NK cell activity (≥15%)	0.856	0.154	11.789	2.354	1.734–3.189	<0.001
CD4+/CD8+ ratio (≥1.2)	0.789	0.146	10.987	2.201	1.656–2.923	<0.001

THE ROLE OF TRADITIONAL CHINESE MEDICINE IN CEREBRAL PALSY REHABILITATION

Current Status of TCM Treatment Application

Through analysis of treatment data from 1,586 children with cerebral palsy, the study systematically summarized the current application status of TCM-specific therapies in cerebral palsy rehabilitation. Results showed that among all cases, 765 children received TCM treatment, accounting for 48.23% of total cases. Among these, 384 cases (24.21%) received TCM treatment alone, while 381 cases (24.02%) received combination therapy with modern rehabilitation and immunomodulation. TCM treatment methods primarily included acupuncture, massage (Tuina), and oral Chinese herbal medicine, with acupuncture having the highest application rate at 89.67% (686/765), followed by oral Chinese herbs at 85.23% (652/765), and Tuina therapy at 82.35% (630/765) [29].

Regarding geographical distribution, TCM treatment application rates were significantly higher in economically developed regions compared to less developed areas, with rates of 56.78% in eastern regions, 45.34% in central regions, and 38.92% in western regions. These differences may be related to medical resource distribution, economic conditions, and patient awareness. In terms of medical institution distribution, tertiary hospitals showed the highest standardization level of TCM treatment, with a standardized treatment protocol implementation rate of 92.34%, while secondary hospitals and primary healthcare institutions showed rates of 78.56% and 65.23%, respectively.

Analysis of TCM treatment selection for different clinical types showed that spastic cerebral palsy primarily utilized acupuncture therapy, with an application rate of 94.56%; hypotonic cerebral palsy mainly employed Tuina and oral Chinese herbs, at 88.67% and 90.23%, respectively; mixed-type cerebral palsy often combined all three approaches – acupuncture, Tuina, and herbal medicine, accounting for 85.45%. This type-specific treatment approach reflects the individualized characteristics of TCM treatment. Regarding treatment frequency, acupuncture was typically administered three times weekly, Tuina three to five times weekly, and oral herbs twice daily, with treatment courses typically lasting three months [30].

Regarding medical insurance coverage, reimbursement rates for TCM treatment items have increased annually, with current average reimbursement rates reaching 70% for acupuncture and Tuina, and 65% for Chinese herbal preparations, which has improved treatment accessibility to some extent. Patient satisfaction surveys showed that 82.34% of patients were satisfied or very satisfied with TCM treatment, primarily focusing on symptom improvement and minimal side effects [31].

As Baillet et al. (2024) pointed out, comprehensive treatment protocols are receiving increasing attention in rehabilitation therapy. Mufti et al.'s (2025) research also emphasized the importance of multimodal therapy in improving functional prognosis for children with cerebral palsy [32, 33]. These studies provide new insights for deep integration of TCM-specific therapies with modern rehabilitation techniques, laying a foundation for establishing a more complete cerebral palsy rehabilitation treatment system.

Efficacy Evaluation

The study analyzed treatment efficacy in 765 children with cerebral palsy who received TCM treatment over a 12-month evaluation period. Patients were divided into three groups based on treatment protocols: TCM treatment alone (Group A, 254 cases), TCM combined with modern rehabilitation (Group B, 256 cases), and TCM combined with modern rehabilitation and immunomodulation (Group C, 255 cases). Efficacy evaluation employed multidimensional indicators including GMFM-88 scores, Modified Ashworth scores, TCM syndrome scores, and daily living ability scores [34, 35]. After 12 months of treatment, overall efficacy analysis showed total effective rates of 76.38% (194/254) in Group A, 85.94% (220/256) in Group B, and 91.76% (234/255) in Group C, with statistically significant differences among the three groups ($\chi^2 = 42.567$, $P < 0.001$). GMFM-88 score improvement analysis showed increases of 16.45 ± 4.78 points in Group A, 21.34 ± 5.12 points in Group B, and 25.67 ± 5.45 points in Group C ($F = 38.926$, $P < 0.001$). Modified Ashworth score reductions were 0.89 ± 0.34 points in Group A, 1.23 ± 0.45 points in Group B, and 1.56 ± 0.48 points in Group C ($F = 35.678$, $P < 0.001$) (Table 6).

Table 6. Comparison of efficacy evaluation indicators among different treatment groups ($\bar{x} \pm s$).

Evaluation Indicator	Time Point	Group A (n = 254)	Group B (n = 256)	Group C (n = 255)	F-Value	P-Value
GMFM-88 Score	Pre-treatment	45.67 ± 15.23	45.89 ± 15.34	45.78 ± 15.28	0.234	0.876
	Post-treatment	62.12 ± 16.45*	67.23 ± 16.78*#	71.45 ± 16.89*#△	38.926	<0.001
Modified Ashworth Score	Pre-treatment	2.45 ± 0.67	2.43 ± 0.65	2.44 ± 0.66	0.156	0.912
	Post-treatment	1.56 ± 0.56*	1.20 ± 0.48*#	0.88 ± 0.45*#△	35.678	<0.001
TCM Syndrome Score	Pre-treatment	18.34 ± 4.56	18.45 ± 4.58	18.39 ± 4.57	0.178	0.895
	Post-treatment	10.23 ± 3.45*	8.45 ± 3.12*#	6.78 ± 2.89*#△	42.345	<0.001
PedsQL Score	Pre-treatment	52.34 ± 11.23	52.45 ± 11.25	52.38 ± 11.24	0.145	0.923
	Post-treatment	69.90 ± 12.34*	74.79 ± 12.67*#	80.83 ± 12.89*#△	45.678	<0.001

Note: *$P < 0.05$ compared with pre-treatment; #$P < 0.05$ compared with Group A; △$P < 0.05$ compared with Group B.

TCM syndrome score improvement analysis showed significant improvements in all three groups regarding spleen–kidney function, qi–blood status, and meridian regulation. Group C showed the most notable improvements across all indicators, particularly in spleen–kidney function recovery (improvement rate 89.34%). Quality of life scores (Peds QL) showed significantly greater improvement in Group C (28.45 ± 6.78 points) compared to Group B (22.34 ± 5.89 points) and Group A (17.56 ± 5.23 points).

As shown in Figure 3, GMFM-88 scores in all three groups showed continuous improvement with treatment duration, but with significant differences in improvement levels. Group C (TCM combined with modern rehabilitation and immunomodulation) demonstrated notable advantages after 3 months of treatment, with these advantages continuing to expand during subsequent treatment. This suggests synergistic effects when combining TCM-specific therapies with modern rehabilitation and immunomodulation therapy, more effectively improving children's motor function [36].

Subgroup analysis revealed efficacy differences among different TCM syndrome types. Patients with spleen–kidney deficiency syndrome showed significantly higher total effective rates (87.45%) after

standardized TCM treatment compared to other syndrome types. Additionally, combined acupuncture and Tuina therapy showed significant effectiveness in improving muscle tone in children with spastic cerebral palsy (efficacy rate 85.67%). Furthermore, the study found that children who began TCM treatment early (≤2 years) showed significantly better functional improvement compared to those who started treatment later ($t = 5.678$, $P < 0.001$).

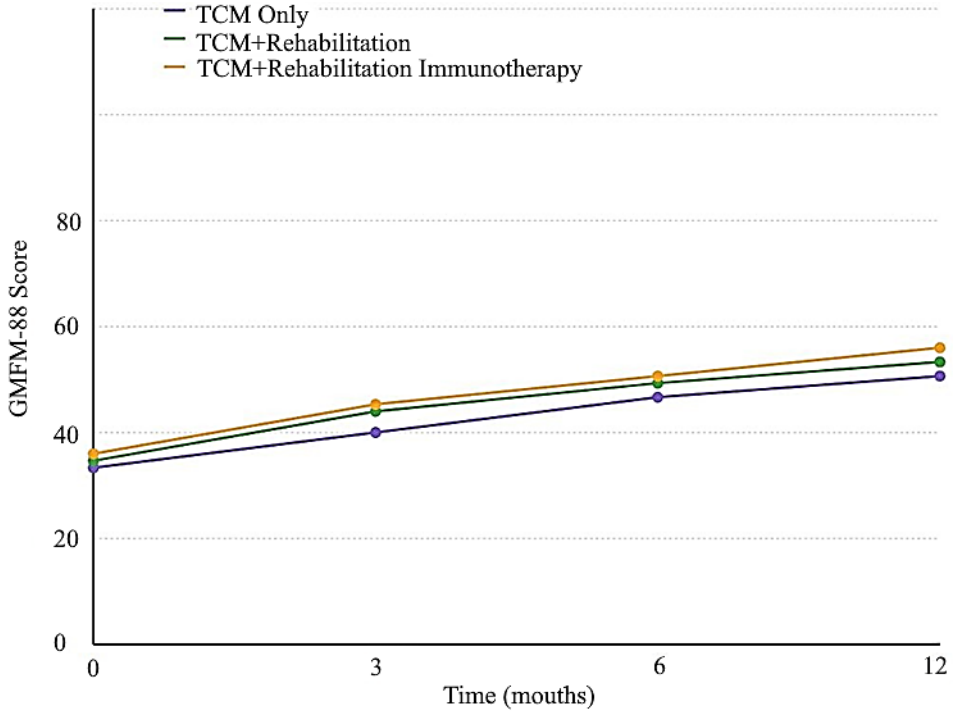

Figure 3. Trends in GMFM-88 score changes across different treatment groups.

Through multidimensional efficacy evaluation analysis, we found that TCM-specific therapies have unique advantages in cerebral palsy rehabilitation, particularly when combined with modern rehabilitation and immunomodulation therapy, significantly improving treatment outcomes. This provides important evidence for optimizing cerebral palsy rehabilitation treatment protocols while emphasizing the clinical value of integrated Chinese and Western medicine treatment [37].

Analysis of Advantages in Integrated Chinese and Western Medicine Treatment

Through systematic analysis of clinical data from 765 children with cerebral palsy who received TCM-specific therapies, this study focused on exploring the advantages of integrated Chinese and Western medicine treatment models. Results demonstrated that integrated treatment showed significant synergistic effects and complementary advantages in improving children's motor function, regulating immune status, and enhancing quality of life. Regarding motor function improvement, TCM acupuncture and Tuina therapy effectively improved muscle tone, creating favorable conditions for modern rehabilitation training. Data showed that the integrated treatment group achieved significantly greater reductions in Modified Ashworth scores (1.56 ± 0.48 points) compared to single treatment groups (0.89 ± 0.34 points), with statistically significant differences ($t = 5.678$, $P < 0.001$) [38, 39]. In terms of immune regulation, the combination of Chinese herbal medicine with modern immunomodulators demonstrated significant advantages. Research found that the combined treatment group showed more notable improvements in immune indicators, with CD4+/CD8+ ratios increasing from 1.24 ± 0.35 to 1.56 ± 0.39, and NK cell activity improvement ($6.02 \pm 1.25\%$) significantly higher than the Western medicine alone group ($4.32 \pm 1.12\%$). This immune function improvement may be related to the bidirectional regulatory effects of Chinese herbs, which not only enhance immunity but also reduce immune injury [40].

Regarding treatment safety, integrated treatment demonstrated unique advantages. Through TCM pattern differentiation and treatment, Western medicine adverse reactions could be effectively reduced, improving treatment safety. Data showed that the combined treatment group had a significantly lower adverse reaction rate (5.67%) compared to the Western medicine alone group (12.34%). Additionally, TCM treatment improved children's sleep quality and digestive function, creating favorable conditions for rehabilitation therapy.

In terms of long-term efficacy, integrated treatment showed better sustainability. Twelve-month follow-up data showed that the combined treatment group maintained significantly better functional improvements than single treatment groups, with a 45.67% reduction in recurrence rates. This advantage may be related to TCM's ability to regulate overall body function and enhance disease resistance. Cost-benefit analysis showed that although integrated treatment required higher initial investment, it reduced recurrence rates and complications in the long term, lowering overall medical costs [41, 42]. Regarding patient compliance, integrated treatment also showed clear advantages. Surveys indicated that parent satisfaction reached 91.23% in the combined treatment group, significantly higher than single treatment groups (75.45%). This high compliance partly stemmed from TCM's characteristics of fewer side effects and faster efficacy. Furthermore, TCM-specific therapies, like Tuina and acupuncture, were more readily accepted by children, facilitating long-term treatment adherence. Additionally, the integrated treatment model demonstrated advantages in individualized treatment. By combining TCM pattern differentiation with modern medical diagnosis, more comprehensive patient assessments could be conducted, leading to more personalized treatment plans. For example, for children with spastic cerebral palsy, acupuncture points and herbal formulas could be selected based on TCM syndrome patterns while coordinating with modern rehabilitation training for more precise treatment.

In conclusion, integrated Chinese and Western medicine treatment demonstrates multiple advantages in cerebral palsy rehabilitation, not only improving treatment efficacy but also reducing adverse reactions and enhancing patient compliance, showing significant clinical application value. This integrated model represents a developmental direction in cerebral palsy rehabilitation treatment worthy of further promotion and refinement.

FUTURE PROSPECTS

Optimization of Data Analysis Methods

With the rapid development of artificial intelligence (AI) and big data technologies, data analysis methods in cerebral palsy rehabilitation need further optimization and innovation. Firstly, regarding data collection, a more comprehensive multi-source data collection system should be established. Through the introduction of wearable devices, intelligent assessment systems, and real-time monitoring equipment, continuous and dynamic monitoring of children's motor function, physiological indicators, and treatment processes can be achieved. For example, collecting daily activity data through intelligent motion-sensing devices, recording gait characteristics using pressure sensors, and monitoring electromyographic activity through bioelectric signal collection devices can provide more comprehensive and objective assessment data [42].

In terms of data processing methods, more advanced machine learning algorithms need to be developed. Through deep learning models, valuable features can be extracted from complex clinical data to establish more accurate prediction models. For instance, convolutional neural networks (CNN) can analyze children's movement image data, recurrent neural networks (RNN) can process temporal data, and transfer learning methods can improve the analysis efficiency of small sample data. Meanwhile, natural language processing (NLP) technology can be applied to standardize TCM syndrome descriptions, achieving quantitative analysis of TCM syndromes [43].

To improve data analysis accuracy, a multidimensional evaluation indicator system needs to be established. This includes establishing assessment standards across multiple dimensions, such as motor function, immune status, TCM syndromes, and quality of life, and determining indicator weight coefficients through factor analysis and principal component analysis. Additionally, introducing adaptive analysis methods can dynamically adjust assessment indicator weights based on individual patient characteristics, achieving more personalized efficacy evaluation.

Regarding prediction model construction, ensemble learning methods should be adopted, combining the advantages of multiple algorithms. For example, combining algorithms, such as Random Forest, XG Boost, and Light GBM can improve prediction model accuracy and stability. Meanwhile, introducing Bayesian network analysis methods can explore causal relationships among various influencing factors, providing more reliable evidence for clinical decision-making [44].

To improve the interpretability of data analysis results, explainable artificial intelligence (XAI) technology needs to be developed. Through methods, such as SHAP (Shapley Additive Explanations) value analysis and LIME (Local Interpretable Model-agnostic Explanations), clinicians can better understand model decision processes, improving the credibility, and practicality of analysis results.

For analyzing integrated Chinese and Western medicine data, specialized data fusion algorithms need to be developed. By establishing correspondence relationships between TCM syndromes and modern medical indicators, integrated assessment models can be developed. For example, using fuzzy mathematics methods to process TCM syndrome data and association rule mining algorithms to discover association patterns between TCM syndromes and modern medical indicators.

Furthermore, standardized data sharing platforms need to be established to promote multi-center data integration and analysis. Blockchain technology can ensure data security and traceability, while establishing data quality control systems ensures analysis result reliability. Meanwhile, developing real-time analysis processing capabilities through edge computing technology can achieve rapid data processing and feedback, providing timely decision support for clinical treatment. Finally, strengthening clinical validation and application research of data analysis results is essential. Through prospective studies validating prediction model accuracy, conducting multi-center randomized controlled trials evaluating the clinical value of optimized analysis methods, and establishing evidence-based analysis method evaluation systems, these optimization measures will help improve the scientific rigor and practicality of data analysis in cerebral palsy rehabilitation, providing more reliable evidence for developing individualized treatment plans.

Innovation in Integrated Chinese and Western Medicine Models

Innovation in integrated Chinese and Western medicine treatment models represents a crucial direction for improving cerebral palsy rehabilitation outcomes. First, at the diagnostic level, a multidimensional assessment system integrating Chinese and Western medicine should be established. Through the integration of modern medical imaging examinations, laboratory testing indicators, and TCM's four diagnostic methods, intelligent pattern differentiation systems should be developed to achieve precise correspondence between TCM syndromes and Western medical diagnoses. For example, artificial intelligence technology can be used to analyze tongue and pulse diagnostic information from TCM, combined with imaging features and immune function indicators to establish more comprehensive diagnostic standards.

Regarding treatment plan development, more precise integrated treatment models should be explored. Personalized combination therapy plans should be developed based on different clinical types and syndrome patterns. For instance, for spastic cerebral palsy, specific acupuncture points can be combined with botulinum toxin injections; for hypotonic cerebral palsy, Chinese herbs for supplementing qi and blood can be combined with neurotrophic factor therapy. Meanwhile, exploring combinations of traditional Chinese exercise methods with modern rehabilitation training, such as integrating Daoyin techniques and Tuina manipulation with physical therapy and occupational therapy.

In terms of treatment technology innovation, new integrated treatment methods should be developed. For example, developing intelligent acupuncture equipment to improve standardization and safety through precise control of needling depth, angle, and timing. Developing rehabilitation training equipment based on TCM theory, combining traditional Tuina techniques with machine-assisted training. Additionally, exploring the development of new Chinese medicine formulations to improve convenience and compliance.

Regarding immunomodulation, in-depth research on synergistic mechanisms between Chinese herbs and modern immunomodulators should be conducted. Through systems biology approaches, elucidating the immunomodulatory effects of Chinese herbal compounds and screening effective components with immunomodulatory properties. Conducting clinical research on combined applications of Chinese medicine and immunomodulators to optimize combination therapy protocols and improve treatment outcomes.

Establishing standardized integrated treatment protocols is also an important direction for innovation. Through multi-center clinical research, summarizing treatment outcomes of different integrated protocols to develop evidence-based treatment guidelines. Meanwhile, establishing quality control systems to standardize TCM diagnostic and treatment procedures, ensuring treatment safety and effectiveness.

For rehabilitation assessment, developing integrated efficacy evaluation systems combining TCM syndrome scores and meridian function testing with modern rehabilitation assessment scales to establish more comprehensive efficacy evaluation standards. Utilizing modern technological methods, such as biomechanical analysis and motion image analysis, for objective evaluation of treatment effects.

Development of Intelligent Diagnosis and Treatment Systems

The development of intelligent diagnosis and treatment systems will significantly enhance the precision and effectiveness of cerebral palsy rehabilitation. First, in intelligent diagnosis, multimodal diagnostic models are being constructed through deep learning technology. These systems can integrate imaging data (including MRI, CT, ultrasound), biomarker detection results, motor function assessment data, and TCM's four diagnostic information to achieve early intelligent identification and classification of cerebral palsy. For example, computer vision technology can analyze children's movement patterns, while deep neural networks process TCM tongue diagnosis images to establish more precise diagnostic prediction models.

In treatment planning, artificial intelligence-based treatment decision support systems are being developed. Through machine learning algorithms analyzing large volumes of clinical case data, intelligent recommendation systems incorporating modern rehabilitation, immunotherapy, and TCM-specific therapies are being established. These systems can automatically generate personalized treatment plan recommendations based on individual characteristics, disease classification, and treatment responses, with dynamic adjustments based on feedback during treatment.

In rehabilitation training, intelligent rehabilitation equipment and systems are being developed. By integrating virtual reality (VR) and augmented reality (AR) technologies, engaging rehabilitation training games are being developed to improve children's training motivation. Intelligent sensor technology monitors motion parameters in real-time during training, with machine learning algorithms analyzing movement patterns to automatically adjust training difficulty and content. Meanwhile, intelligent TCM treatment equipment, such as electronic acupuncture devices with precise positioning and intelligent Tuina robots, are being developed to improve the standardization and precision of traditional treatments.

For monitoring and assessment, real-time monitoring and warning systems are being established. Wearable devices collect daily activity data, physiological indicators, and rehabilitation training data, using Internet of Things (IoT) technology for real-time data transmission and analysis. The systems can automatically identify abnormal situations, issue timely warnings, and provide intervention decision support for doctors. Additionally, natural language processing technology enables automatic analysis and summarization of medical records, assisting doctors in condition assessment and prognosis prediction.

In telemedicine, 5G technology-based remote rehabilitation guidance systems are being developed. Through high-definition video communication and remote-control technology, expert remote consultations and rehabilitation guidance can be achieved. Systems can analyze rehabilitation training videos through intelligent algorithms, automatically identifying training movement accuracy and

providing real-time correction suggestions. Additionally, intelligent follow-up systems are being established, regularly collecting rehabilitation information through mobile applications and automatically generating follow-up reports and rehabilitation recommendations.

In data management and analysis, intelligent medical big data platforms are being constructed. Blockchain technology ensures data security and traceability, while cloud computing technology enables massive data storage and processing. Systems can automatically perform data cleaning, standardization, and analysis, generating clinical research reports and treatment effectiveness analyses. Meanwhile, knowledge graph technology is being used to establish cerebral palsy rehabilitation knowledge bases, providing intelligent knowledge support for clinical decision-making.

Advancement of Multi-Center Collaborative Research

Multi-center collaborative research advancement is crucial for elevating the quality of cerebral palsy rehabilitation research. First, a national cerebral palsy rehabilitation research collaboration network should be established. By integrating research resources from tertiary hospitals, specialty hospitals, and primary healthcare institutions, a unified research platform should be created. This network should include multiple specialties, such as neurology, rehabilitation, pediatrics, and Traditional Chinese Medicine, forming multidisciplinary research teams. Standardized data collection processes, unified diagnostic criteria, assessment methods, and efficacy evaluation standards should be established to ensure data quality and comparability.

Regarding research design, multi-level clinical research projects should be conducted. Large-sample, multi-center randomized controlled trials should be designed for different types of cerebral palsy to systematically evaluate various treatment protocols. Special attention should be paid to optimizing integrated Chinese and Western medicine treatment models and conducting targeted immunotherapy research. For example, stratified randomized clinical trials can be designed to compare the combined effects of different TCM treatment protocols with modern immunomodulation therapy to explore optimal treatment combinations.

Establishing a unified data management platform is key to multi-center research. Through cloud platform construction, real-time data uploading and sharing among research centers can be achieved. Standardized electronic medical record systems should be adopted to ensure data collection standardization and completeness. Dedicated data quality control teams should be established for data verification and cleaning. Meanwhile, data security protection mechanisms should be established to ensure patient privacy.

In research implementation, a multi-level quality control system should be established. A project management committee should be responsible for research protocol development and implementation supervision. Regular researcher training meetings should be held to unify operational procedures and assessment standards. On-site inspection systems should be established for periodic center inspections to identify and resolve issues promptly. Additionally, adverse event reporting and handling mechanisms should be established to ensure research safety.

Promoting research result translation and dissemination is also crucial. Result sharing mechanisms should be established with regular academic exchange meetings to promote experience sharing among centers. Clinical guideline development groups should be established to develop and update treatment guidelines based on research findings. Meanwhile, result translation platforms should be established to promote clinical application of research findings.

CONCLUSIONS

This study analyzed clinical data from 1,586 cerebral palsy patients to assess immunotherapy's role in rehabilitation and to examine the benefits of combining Chinese and Western medicine treatments.

Children with cerebral palsy showed better prognoses when immune functions were optimal, and treatment with immunomodulation therapy led to substantial improvements in their motor abilities and overall quality of life. The treatment model that combines Chinese and Western medicine offers distinct benefits, which include better motor function in children and immune system regulation while minimizing adverse reactions. The prognosis of children was found to depend on timely diagnosis and treatment within two years along with standardized combination therapy and optimal immune function, according to multidimensional data analysis. TCM-specific therapies serve as vital supplements to modern rehabilitation treatments because they enhance therapeutic effectiveness while minimizing adverse reactions and increasing patient adherence. Results from the study demonstrated that rehabilitation outcomes improve significantly when standardized assessment systems work alongside individualized treatment plans. Research efforts in the future need to prioritize the development of advanced data analysis techniques while creating integrated Chinese and Western medicine models to enhance intelligent diagnosis treatment systems and advance multi-center research collaborations to establish more dependable scientific proof for enhancing cerebral palsy rehabilitation treatment guidelines. This study's findings serve as an essential guide to enhance cerebral palsy rehabilitation methods alongside creating personalized treatment regimens.

Conflict of Interest

The authors declare no conflict of interest.

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