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Original Article

Combined core stability and nutritional therapy are associated with greater functional and nutritional gains in children with spastic cerebral palsy

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Abstract: Objective: To compare 12-month functional and nutritional outcomes among children with spastic cerebral palsy receiving conventional rehabilitation, rehabilitation plus individualized nutrition, or rehabilitation plus nutrition and core stability training. Methods: This single-center retrospective cohort included 60 children aged 3-12 years with Gross Motor Function Classification System levels I-IV (20 per group). Core training was delivered three times weekly for 30 minutes during a 3-month supervised phase, and nutrition followed an individualized five-step protocol. Outcomes were assessed at baseline and 3, 6, and 12 months. Continuous outcomes were analyzed by repeated-measures and time-specific analysis of variance with Holm-adjusted comparisons. Ordinal outcomes were analyzed non-parametrically. Results: Age and sex were comparable at baseline. Group-by-time interactions were observed for Gross Motor Function Measure-88 Dimension D (P=0.026), Dimension E (P=0.048), Berg Balance Scale (P<0.01), weight-for-age z-score (P<0.001), and body mass index-for-age z-score (P<0.01). At 12 months, the combined group exceeded the conventional group in Dimension D by 14.11 points (95% CI 6.50-21.72; Holm P=0.002), Dimension E by 13.54 points (95% CI 6.39-20.69; Holm P<0.001), and balance by 11.29 points (95% CI 5.02-17.56; Holm P=0.002). Weight-for-age and body mass index-for-age z-scores were higher by 2.35 and 1.99 units (both Holm P<0.001). Spasticity was lower and strength was higher in the combined group. No serious intervention-related adverse events were documented. Conclusions: Comprehensive rehabilitation was associated with larger functional and nutritional gains, but causality could not be established. A stratified randomized trial with blinded assessment and quantified adherence is warranted.

Keywords: Cerebral palsy, core stability, trunk control, nutritional therapy, gross motor function, GMFM-88, balance, retrospective cohort

Introduction

Cerebral palsy (CP) comprises permanent disorders of movement and posture caused by non-progressive disturbances in the developing fetal or infant brain [1]. It is the most common physical disability of childhood. Contemporary estimates indicate an overall prevalence of approximately 1.6 per 1,000 live births in high-income settings, with higher estimates in many low- and middle-income settings [2-5]. Because spastic CP is a subtype rather than the entire CP population, the prevalence of all CP should not be presented as a subtype-specific estimate.

Spastic CP is characterized by velocity-dependent hypertonia, muscle weakness, impaired selective motor control, and deficient postural control. These impairments restrict standing, walking, and participation in daily activities. The Gross Motor Function Measure-88 (GMFM-88) is widely used to quantify change in children with CP; Dimension D assesses standing, whereas Dimension E assesses walking, running, and jumping. The instrument has excellent inter-rater and test-retest reliability and is responsive to clinically meaningful motor change [6-8].

Conventional rehabilitation commonly combines neurodevelopmental treatment, task practice, stretching and peripheral strengthening. However, an intervention that focuses mainly on the limbs may insufficiently address

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proximal postural control. Trunk stability provides a dynamic base for distal movement, and a center-to-periphery training strategy is consistent with the proximal-to-distal organization of motor development [9, 10].

Evidence supporting trunk-focused rehabilitation is increasing. Systematic reviews and randomized trials of trunk training, core stability exercise, dynamic-surface training, functional strengthening, modified Pilates and dual-task practice have reported improvements in trunk control, standing, balance, and gait relative to conventional physiotherapy alone [10-15]. Surface electromyography can provide objective neuromuscular measures in this field, but its value depends on prespecified acquisition procedures and complete quantitative reporting [16-19].

Nutritional status is an additional determinant of rehabilitation capacity. Children with CP may experience undernutrition because of dysphagia, prolonged mealtimes, insufficient intake, gastrointestinal symptoms, elevated care burden and recurrent illness. Low weight-for-age and body mass index-for-age z-scores, micronutrient deficiency and anemia are common in some cohorts [20-23]. Structured nutrition interventions, including caregiver education, dietary fortification, oral nutritional supplements and enteral feeding when indicated, can improve growth and may support motor function [24-28].

The combined relationship between proximal motor control and nutrition has not been adequately examined in children with spastic CP. This retrospective cohort therefore compared three increasingly comprehensive routine-care strategies: conventional rehabilitation, conventional rehabilitation plus individualized nutritional therapy and conventional rehabilitation plus nutritional therapy and core stability training. We hypothesized that the combined program would be associated with the largest 12-month improvements in standing, locomotion, balance, spasticity, strength, and nutritional status.

Materials and methods

Study design and ethical approval

This single-center retrospective cohort study reviewed records from June 2024 through December 2025. The study was approved by the Medical Ethics Committee of Xiaoyi Special Education School (No. TSIY-2024-001). The requirement for informed consent was waived because only anonymized routine-care data were analyzed and no intervention was assigned for research purposes. Privacy safeguards were applied throughout data extraction and reporting followed the principles of the Strengthening the Reporting of Observational Studies in Epidemiology statement.

Participants

Eligibility criteria: Eligible records were from children aged 3-12 years with a clinical diagnosis of spastic CP, Gross Motor Function Classification System (GMFCS) level I-IV, intelligence quotient of at least 70, no previous structured core stability program and complete baseline and follow-up outcome records. Children were excluded for poorly controlled epilepsy, severe visual or auditory impairment, severe cognitive impairment that prevented standardized assessment, major internal-organ disease, surgery during the observation period, incomplete records, or documented poor participation in routine rehabilitation.

Sample size and grouping: GMFM-88 Dimension D was designated as the primary motor outcome because standing control directly reflected the proximal-to-distal target of the intervention. Assuming a clinically relevant 10-point between-group difference, a standard deviation of 15 points, a two-sided alpha of 0.05, and 80% power, at least 17 children per group were required. Allowing for approximately 15% incomplete records yielded a target of 20 records per group. All 60 eligible records were included and classified according to the routine rehabilitation program received: conventional rehabilitation, rehabilitation plus nutrition, or rehabilitation plus nutrition and core stability training. Age and sex were formally evaluated for baseline comparability. GMFCS level was retained as an eligibility descriptor, but level-specific documentation was not sufficiently complete for a reliable group-by-group statistical table.

Interventions

All children continued clinically indicated medical care and conventional rehabilitation. The groups differed in the additional program components described below.

Conventional group: Children in the conventional group received 40-minute rehabilitation sessions on treatment days. The routine program included Bobath-based facilitation, range-of-motion activities, functional task practice and peripheral muscle strengthening. No structured trunk-specific exercise program or formal individualized nutrition pathway was documented beyond routine dietary advice.

Nutrition group: Children in the nutrition group received conventional rehabilitation and an individualized dietitian-led nutrition program. Nutritional risk screening, anthropometry, feeding history, gastrointestinal symptoms, food texture and caregiver-reported intake were reviewed at baseline and follow-up [28]. Energy targets were based on age- and sex-specific requirements and were adjusted for growth trajectory, activity level, clinical condition, feeding tolerance and the need for catch-up growth. Protein targets were aligned with age-specific reference intake and increased when undernutrition or tissue recovery justified a higher target. The five-step escalation pathway comprised optimization of the habitual diet with energy- and protein-dense foods, oral fortification and texture modification, oral nutritional supplements when food intake remained inadequate, tube feeding when oral intake was unsafe or insufficient, and intensive caregiver support for complex feeding situations. Quantitative intake adequacy, feeding-record completion and oral-supplement consumption percentages were not uniformly documented in the retrospective records and were therefore not analyzed as outcomes.

Combined group: Children in the combined group received conventional rehabilitation, the same individualized nutrition pathway and supervised core stability training three times weekly for 30 minutes during the 3-month center-based phase. Sessions were delivered by a pediatric physiotherapist and followed a center-to-periphery sequence. A typical session included approximately 5 minutes of preparatory alignment and breathing control, 20 minutes of progressive trunk exercise and 5 minutes of functional transfer and recovery activities. The exercise circuit included supine abdominal bracing and pelvic control, bridging, side-lying trunk activation, prone-on-elbows or modified plank tasks, quadruped weight shifting and assisted contralateral reaching, supported sitting and standing reach, kneeling and half-kneeling control, sit-to-stand practice, balance tasks on compliant surfaces, and graded anticipatory or therapist-applied perturbations. Training generally began with one to two sets of 8-10 repetitions or 15-20-second holds at a perceived exertion of approximately 3-4/10. It progressed toward two to three sets of 10-15 repetitions or holds of up to 30 seconds at approximately 5-6/10 by reducing external support, narrowing the base of support, increasing reach distance, adding unstable surfaces, or increasing perturbation complexity. Progression required safe alignment and successful completion of at least 80% of the assigned task in two consecutive sessions. The structured supervised core phase lasted 3 months; conventional rehabilitation remained available as routine care and caregivers were instructed to continue the individualized nutrition plan and selected home exercises during follow-up. The retrospective records did not contain sufficiently complete percentage-based adherence data for the home phase.

Outcome measures and data extraction

Outcome data were extracted at baseline and at 3, 6, and 12 months. Assessments had been completed by trained rehabilitation staff using standardized procedures. Data were double-entered and cross-checked against the source record. The primary outcome was GMFM-88 Dimension D. Secondary outcomes were GMFM-88 Dimension E, balance, lower-limb spasticity, muscle strength, weight-for-age z-score, body mass index-for-age z-score, and adverse events.

Gross motor function: Gross motor function was assessed with the GMFM-88. Dimension D quantifies standing and Dimension E quantifies walking, running, and jumping. Scores are expressed as percentages, with higher scores indicating better function [6-8]. The GMFM-88 total score was not used as an analytic endpoint because the available longitudinal extraction focused on Dimensions D and E.

Balance: Balance was assessed with the 14-item Berg Balance Scale (BBS), which ranges from 0 to 56 points; higher scores indicate

Table 1. Baseline demographic characteristics of the three groups

Group	n	Age (years)	Male, n	Female, n
Conventional	20	8.20 ± 2.98	12	8
Nutrition	20	8.40 ± 3.24	9	11
Combined	20	8.25 ± 2.85	11	9
F or χ^2 value		0.024	0.938	
P value		0.977	0.626	

Data are mean ± standard deviation or counts. GMFCS levels I-IV were eligibility criteria, but level-specific distributions were not sufficiently complete for a reliable between-group table.

better balance. The pediatric adaptation has excellent reliability and established validity in children with CP [29, 30].

Spasticity and muscle strength: Lower-limb spasticity was graded with the Modified Ashworth Scale (MAS), and muscle strength was graded with Manual Muscle Testing (MMT). Because both scales are ordinal, values were summarized as median and interquartile range and were analyzed with rank-based methods.

Nutritional status: Nutritional status was assessed with weight-for-age z-score (WAZ) and body mass index-for-age z-score (BAZ). Weight and height were converted to age- and sex-standardized values using World Health Organization standards and references [31, 32].

Safety and adherence: Adverse events documented during rehabilitation or follow-up were extracted from the medical record. Quantitative adherence proportions were reported only when consistently available; because percentage-based core-session attendance, home-exercise completion, feeding-record completion, and oral-supplement intake were incomplete, these variables were not included in inferential analyses.

Statistical analysis

Statistical analyses were performed with SPSS version 25.0. Distributional assumptions were evaluated with histograms, Q-Q plots, and the Shapiro-Wilk test. Normally distributed continuous data are presented as mean ± standard deviation, non-normally distributed or ordinal data as median (interquartile range) and categorical data as number and percentage. Baseline age was compared by one-way analysis of variance (ANOVA) and sex by the chi-square test. GMFM-88 Dimensions D and E, BBS, WAZ, and BAZ were evaluated with repeated-measures ANOVA including group, time, and group-by-time interaction terms. Sphericity was assessed and Greenhouse-Geisser correction was used when required. To clarify the time points responsible for group differences, one-way ANOVA was performed at each assessment and pairwise pooled-variance t tests were corrected with the Holm procedure. Twelve-month mean differences are presented with 95% confidence intervals calculated from the reported group means, standard deviations and sample sizes. MAS and MMT were compared among groups with the Kruskal-Wallis H test and within groups with the Wilcoxon signed-rank test. All tests were two-sided and $P<0.05$ was considered significant. No outcome data were imputed because complete records were required for inclusion.

Results

Baseline characteristics

Sixty children with spastic CP were included, with 20 children in each group. Age and sex were comparable among groups (both $P>0.05$; **Table 1**). Baseline values of the reported motor, balance, tone, strength and nutritional outcomes were also similar. GMFCS level-specific counts were not analyzed because the retrospective records did not support a reliable level-by-level distribution table.

Gross motor function

GMFM-88 Dimension D improved over time in all groups, with a group-by-time interaction of $P=0.026$ (**Table 2**). The time-specific omnibus test was not significant at baseline ($F=0.04$, $P=0.961$) but was significant at 3 months ($F=4.34$, $P=0.018$), 6 months ($F=5.57$, $P=0.006$) and 12 months ($F=7.46$, $P=0.001$). After Holm correction, the combined group exceeded the conventional group by 8.72 points at 3 months ($P=0.029$), 11.28 points at 6 months ($P=0.005$), and 14.11 points at 12 months (95% CI 6.50-21.72; $P=0.002$). The combined group also exceeded the nutrition group at 6 months ($P=0.013$) and 12 months (difference

Table 2. Gross motor function measure-88 dimension D and dimension E scores over time

Outcome/group	Baseline	3 months	6 months	12 months
Dimension D (standing)				
Conventional (n=20)	52.18 ± 10.16	55.64 ± 11.38	59.23 ± 13.99	64.74 ± 15.83
Nutrition (n=20)	52.82 ± 5.91	58.20 ± 8.53	61.92 ± 12.15	68.33 ± 12.26
Combined (n=20)	52.18 ± 8.33	64.36 ± 8.68	70.51 ± 5.55	78.85 ± 5.64
Between-group F (2, 57)	0.04	4.34	5.57	7.46
Between-group P	0.961	0.018	0.006	0.001
Group × time interaction P	0.026			
Dimension E (walking/running/jumping)				
Conventional (n=20)	43.68 ± 15.92	46.18 ± 15.83	52.71 ± 18.20	59.79 ± 14.89
Nutrition (n=20)	44.37 ± 11.78	49.72 ± 10.00	54.58 ± 12.89	62.50 ± 10.99
Combined (n=20)	42.71 ± 14.32	52.71 ± 9.57	63.40 ± 10.44	73.33 ± 5.30
Between-group F (2, 57)	0.07	1.45	3.23	8.31
Between-group P	0.933	0.243	0.047	<0.001
Group × time interaction P	0.048			

Values are mean ± standard deviation. Interaction *P* values are listed independently and refer to the repeated-measures analysis. Time-specific F and *P* values are from one-way ANOVA. Pairwise comparisons reported in the text were adjusted with the Holm procedure.

10.52 points, 95% CI 4.41-16.63; P=0.003), whereas the 3-month comparison was not significant after correction.

Dimension E showed a smaller early separation but a clear later difference, with a group-by-time interaction of P=0.048. The omnibus between-group test was significant at 6 months (F=3.23, P=0.047) and 12 months (F=8.31, P<0.001). Holm-adjusted pairwise comparisons were not significant at 3 or 6 months. At 12 months, the combined group exceeded the conventional group by 13.54 points (95% CI 6.39-20.69; P<0.001) and the nutrition group by 10.83 points (95% CI 5.31-16.35; P<0.001). The longitudinal changes and 12-month effect estimates are summarized in **Figure 1**.

Balance

BBS scores increased in all groups, with a significant time effect and group-by-time interaction (both P<0.01; **Table 3**). Between-group differences were not significant at baseline or 3 months, became significant at 6 months (F=3.45, P=0.039) and remained significant at 12 months (F=5.80, P=0.005). The combined group exceeded the conventional group at 6 months (Holm P=0.030) and by 11.29 points at 12 months (95% CI 5.02-17.56; Holm P=0.002). The 12-month difference between the combined and nutrition groups was 6.05 points (95% CI 0.19-11.91), but it did not remain significant after multiplicity correction (Holm P=0.087). **Figure 2** presents change from baseline and the 12-month effect estimates.

Spasticity and muscle strength

Lower-limb MAS values were comparable at baseline (H=0.146, P=0.929) and differed at 12 months (H=29.24, P<0.001), when the combined group had a median of 1.0 compared to 2.0 in the other groups (**Table 4**). Within-group reductions were significant in every group (all P<0.01). MMT values were also comparable at baseline (H=0.010, P=0.995) and differed at 12 months (H=9.09, P=0.011), when the combined group reached a median grade of 4.0 and the other groups reached 3.0. Within-group increases were significant in all groups (all P<0.001). Identical group medians at some assessments do not indicate that individual scores were unchanged; the ordinal scales have few categories, and paired rank tests were based on participant-level changes that may not have altered the group median.

Nutritional status

WAZ increased in all groups and showed a group-by-time interaction of P<0.001 (**Table 5**). The groups were comparable at baseline and 3 months, but the omnibus difference was signifi-

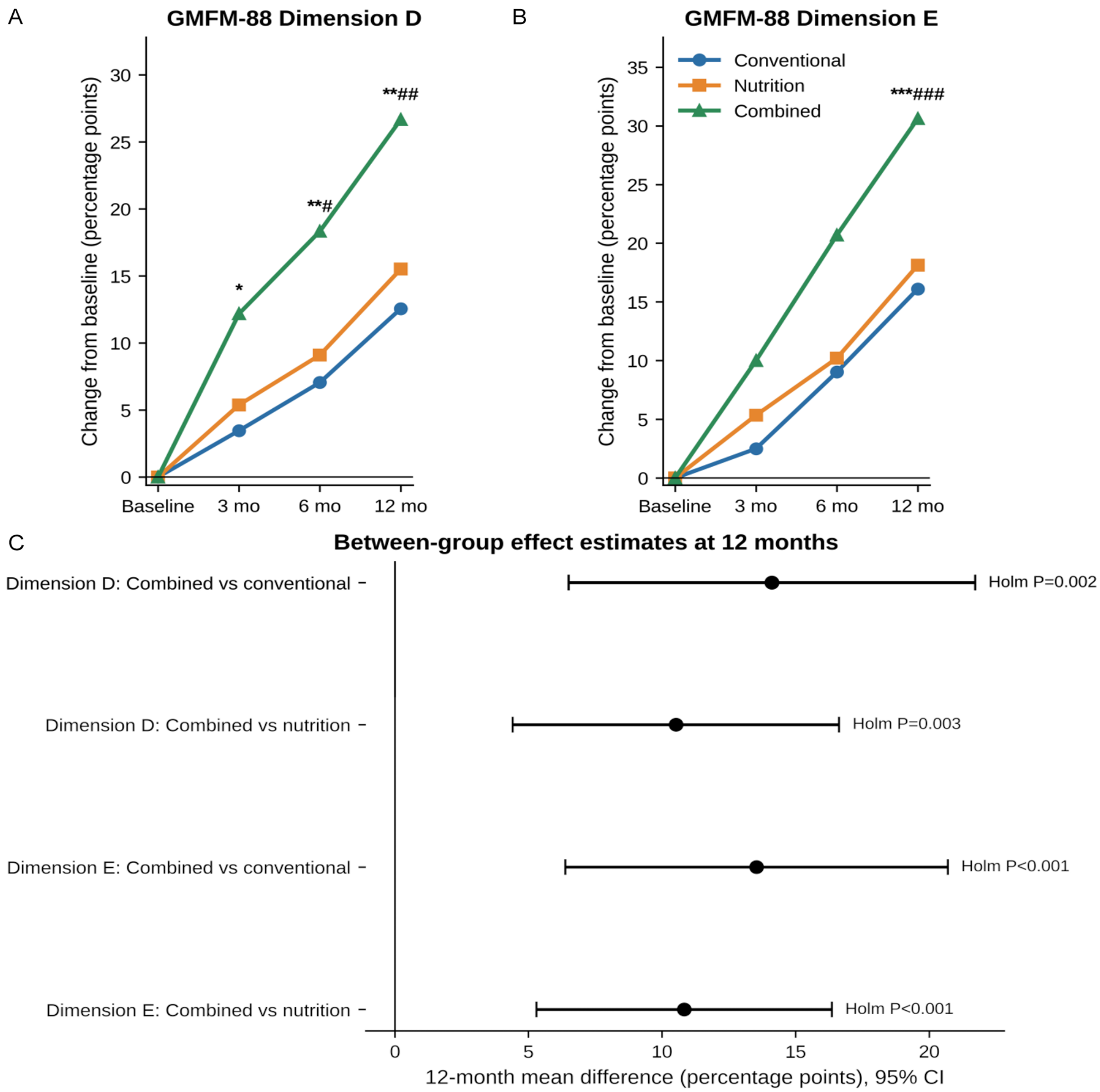

Figure 1. Gross motor function measure-88 (GMFM-88) results. (A) and (B) show group mean changes from baseline for Dimensions D and E. (C) shows 12-month mean differences with unadjusted 95% confidence intervals; pairwise *P* values were adjusted by the Holm procedure. *P<0.05, **P<0.01, ***P<0.001 versus conventional rehabilitation; #P<0.05, ##P<0.01, ###P<0.001 versus nutrition. Time-specific tests used one-way analysis of variance followed by Holm-adjusted pooled-variance t tests.

Table 3. Berg balance scale scores over time

Group/statistic	Baseline	3 months	6 months	12 months
Conventional (n=20)	18.84 ± 11.89	21.42 ± 13.02	25.32 ± 13.02	30.21 ± 12.75
Nutrition (n=20)	22.70 ± 10.14	26.80 ± 9.96	31.20 ± 12.02	35.45 ± 11.74
Combined (n=20)	21.15 ± 9.92	29.80 ± 8.76	34.40 ± 7.44	41.50 ± 5.44
Between-group F (2, 57)	0.66	3.13	3.45	5.80
Between-group P	0.520	0.051	0.039	0.005
Time effect F	167.24			
Group × time interaction F	5.96			
Group × time interaction P	<0.01			

Values are mean ± standard deviation. Time-specific F and *P* values are from one-way ANOVA. Pairwise comparisons reported in the text were adjusted with the Holm procedure.

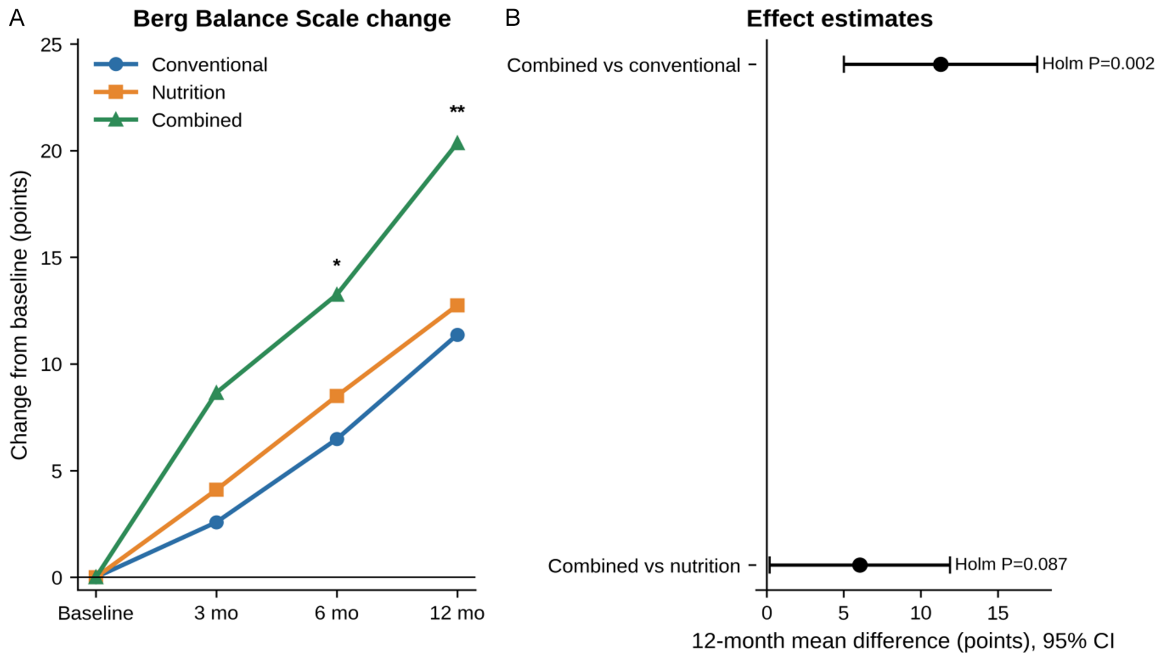

Figure 2. Berg balance scale results. (A) shows group mean change from baseline, and (B) shows 12-month mean differences with unadjusted 95% confidence intervals. *P<0.05 and **P<0.01 versus conventional rehabilitation after Holm correction. Time-specific tests used one-way analysis of variance followed by Holm-adjusted pooled-variance t tests.

Table 4. Modified Ashworth scale and manual muscle testing at baseline and 12 months

Outcome/group	Baseline	12 months
Modified Ashworth Scale		
Conventional	3.0 (2.0-3.0)	2.0 (2.0-3.0)
Nutrition	3.0 (3.0-3.0)	2.0 (2.0-3.0)
Combined	3.0 (2.25-3.75)	1.0 (1.0-1.0)
Kruskal-Wallis H (P)	0.146 (0.929)	29.24 (<0.001)
Manual Muscle Testing		
Conventional	2.0 (1.0-3.0)	3.0 (2.0-3.75)
Nutrition	2.0 (1.0-3.0)	3.0 (2.25-4.0)
Combined	2.0 (1.0-3.0)	4.0 (4.0-5.0)
Kruskal-Wallis H (P)	0.010 (0.995)	9.09 (0.011)

Values are median (interquartile range). Within-group changes were significant in all groups (Wilcoxon signed-rank test: P<0.01 for Modified Ashworth Scale and P<0.001 for Manual Muscle Testing). Unchanged group medians may coexist with participant-level paired changes because these scales are ordinal and have few categories.

cant at 6 months (F=25.45, P<0.001) and 12 months (F=125.89, P<0.001). At 12 months, the combined group had a mean WAZ of +0.48 compared to -1.87 in the conventional group and -1.18 in the nutrition group. The corresponding mean differences were 2.35 z-score units (95% CI 2.06-2.64; Holm P<0.001) and 1.66 units (95% CI 1.34-1.98; Holm P<0.001).

BAZ followed a similar pattern, with a group-by-time interaction of P<0.01. The between-group difference was significant at 6 months (F=28.96, P<0.001) and 12 months (F=87.08, P<0.001). At 12 months, the combined group had a mean BAZ of +0.08 compared to -1.91 in the conventional group and -0.71 in the nutrition group. The corresponding mean differences were 1.99 units (95% CI 1.69-2.29; Holm P<0.001) and 0.79 units (95% CI 0.49-1.09; Holm P<0.001). **Figure 3** presents changes from baseline and 12-month effect estimates. Hemoglobin was not retained as an outcome because it was not prespecified in the available outcome extraction.

Safety and adherence

No serious adverse event attributable to core stability training or nutritional therapy was documented during the 12-month observation

Table 5. Weight-for-age and body mass index-for-age z-scores over time

Index/group	Baseline	3 months	6 months	12 months
Weight-for-age z-score				
Conventional	-2.42 ± 0.34	-2.26 ± 0.41	-2.08 ± 0.44	-1.87 ± 0.44
Nutrition	-2.46 ± 0.33	-2.13 ± 0.49	-1.68 ± 0.52	-1.18 ± 0.53
Combined	-2.42 ± 0.32	-2.08 ± 0.33	-1.04 ± 0.43	+0.48 ± 0.47
Between-group F (2, 57)	0.10	1.00	25.45	125.89
Between-group P	0.907	0.374	<0.001	<0.001
Group × time interaction P	<0.001			
Body mass index-for-age z-score				
Conventional	-2.25 ± 0.35	-2.18 ± 0.42	-1.99 ± 0.46	-1.91 ± 0.49
Nutrition	-2.24 ± 0.36	-2.14 ± 0.41	-1.49 ± 0.46	-0.71 ± 0.49
Combined	-2.30 ± 0.28	-1.97 ± 0.37	-0.90 ± 0.44	+0.08 ± 0.46
Between-group F (2, 57)	0.19	1.55	28.96	87.08
Between-group P	0.829	0.221	<0.001	<0.001
Group × time interaction P	<0.01			

Values are mean ± standard deviation. Interaction *P* values are listed independently and refer to the repeated-measures analysis. Time-specific F and *P* values are from one-way ANOVA. Pairwise comparisons reported in the text were adjusted with the Holm procedure.

period. The available records did not permit reliable percentage-based comparisons of center attendance, home exercise, feeding-record completion, or oral nutritional supplement consumption.

Discussion

This retrospective cohort study found that increasingly comprehensive routine-care programs were associated with progressively larger improvements in motor function, balance, spasticity, strength, and nutritional status. The combined program had the largest 12-month differences in GMFM-88 Dimensions D and E, BBS, WAZ and BAZ. These findings are associations rather than estimates of causal treatment efficacy because program allocation was not randomized.

The motor pattern is consistent with the biomechanical rationale for trunk-focused rehabilitation. A controlled trunk provides a stable base for selective limb movement and supports anticipatory and reactive postural adjustments. The larger Dimension D difference and the later emergence of the Dimension E difference are clinically plausible: gains in proximal alignment and standing control may precede more demanding walking, running and jumping tasks. This sequence is broadly consistent with systematic reviews and randomized trials of trunk training, core stability exercise, modified Pilates, dynamic-surface practice, and dual-task rehabilitation [9-15]. Unlike those controlled studies, however, the present analysis cannot separate the core program from differences in motivation, caregiver involvement, or concurrent care.

The balance results strengthen this interpretation. The combined group separated from conventional rehabilitation by 6 months and retained an 11-point advantage at 12 months, whereas nutrition alone produced a smaller and statistically less consistent difference. Improved trunk alignment, controlled weight shift and perturbation practice can increase the limits of stability required for standing and locomotion. Future trials should include blinded assessment and prespecified instrumented measures; surface electromyography may be informative only when acquisition, normalization, muscles, tasks, and statistical outputs are completely reported [16-19].

The nutritional findings are also compatible with prior evidence that structured nutrition support improves growth in undernourished children with CP [20-28]. The supervised 3-month phase did not necessarily represent cessation of all care: conventional rehabilitation remained available, caregivers were instructed to continue the individualized nutrition

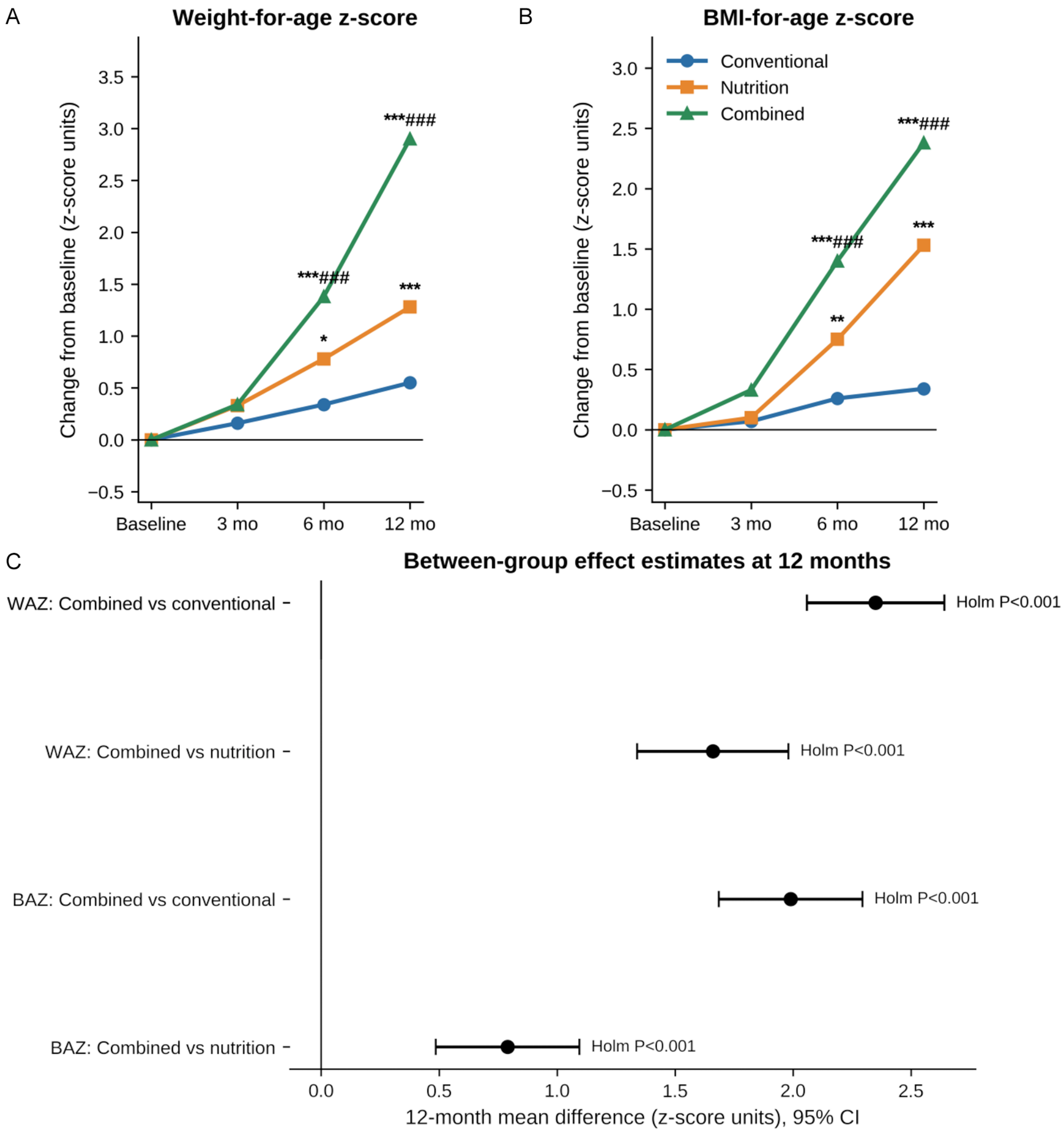

Figure 3. Nutritional outcomes. (A) and (B) show group mean changes from baseline for weight-for-age z-score (WAZ) and body mass index-for-age z-score (BAZ). (C) shows 12-month mean differences with unadjusted 95% confidence intervals. *P<0.05, **P<0.01, ***P<0.001 versus conventional rehabilitation; ###P<0.001 versus nutrition after Holm correction. Time-specific tests used one-way analysis of variance followed by Holm-adjusted pooled-variance t tests.

plan and selected home exercises and routine follow-up could reinforce feeding strategies. Biological maintenance could reflect sustained energy and protein adequacy, catch-up growth from a low baseline, improved feeding posture, reduced mealtime fatigue, or greater participation in active play. Nevertheless, the magnitude of the WAZ and BAZ changes, including transition from negative to slightly positive group means, requires cautious interpretation.

Regression to the mean is a particular concern because all groups began with low nutritional z-scores and the study was retrospective. Extreme values, selective completeness of follow-up records, and unmeasured differences in feeding severity or caregiver resources could have enlarged the apparent group separation. The aggregate dataset did not permit participant-level influence diagnostics, trimmed-mean analyses, or exclusion of extreme observations. Therefore, the nutritional estimates should be treated as hypothesis-generating rather than definitive evidence that the combined intervention normalized growth.

The study had several limitations. It was conducted at one center, included only 20 children per group, and used non-random program allocation, leaving residual confounding and selection bias. GMFCS level-specific distributions were incompletely documented, quantitative nutrition and home-exercise adherence were unavailable, and the duration and intensity of care after the supervised phase could not be fully quantified. MAS and MMT were coarse ordinal measures. The analysis involved multiple outcomes and time-specific comparisons, although Holm correction was applied to pairwise tests. Surface electromyography and hemoglobin were excluded from the final outcome set because the available records did not support complete prespecified quantitative analyses. Finally, participant-level sensitivity analyses for extreme nutritional values were not possible.

A confirmatory randomized controlled trial should use stratified randomization by age and GMFCS level, concealed allocation, blinded assessors, a standardized and fully replicable core protocol, quantified supervised and home adherence, prospective food records and oral-supplement consumption, and prespecified adverse-event monitoring. Repeated anthropometry should be quality controlled and an intention-to-treat mixed-effects model should account for within-child correlation and missing data. A 12-month follow-up should distinguish the supervised phase from maintenance exposure and test whether functional and nutritional gains persist.

In conclusion, conventional rehabilitation combined with individualized nutritional therapy and core stability training was associated with greater 12-month functional and nutritional gains than less comprehensive routine-care programs in children with spastic CP. The findings support prospective evaluation of an integrated center-to-periphery rehabilitation model but do not establish causality.

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Disclosure of conflict of interest

None.

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References

[1] Rosenbaum P, Paneth N, Leviton A, Goldstein M, Bax M, Damiano D, Dan B and Jacobsson B. A report: the definition and classification of cerebral palsy April 2006. Dev Med Child Neurol Suppl 2007; 109: 8-14.
[2] Novak I, Jackman M, Finch-Edmondson M and Fahey M. Cerebral palsy. Lancet 2025; 406: 174-188.
[3] McIntyre S, Goldsmith S, Webb A, Ehlinger V, Hollung SJ, McConnell K, Arnaud C, Smithers-Sheedy H, Oskoui M, Khandaker G and Himmelmann K; Global CP Prevalence Group. Global prevalence of cerebral palsy: a systematic analysis. Dev Med Child Neurol 2022; 64: 1494-1506.
[4] Olusanya BO, Nair MKC, Boo NY, Davis AC, Hadders-Algra M and Wright SM; Global Research on Developmental Disabilities Collaborators. Cerebral palsy in young children: bridging the global data gap. Lancet Glob Health 2025; 13: e1663-e1664.
[5] Valluri H, Mohanty M, Mongil CR, Fuentes G, Sultan T and Torres AR. Investigating the burden of cerebral palsy in low- and middle-income countries: implications and priorities for pediatric neurology. Semin Pediatr Neurol 2025; 55: 101225.
[6] Ko J and Kim M. Reliability and responsiveness of the Gross Motor Function Measure-88 in children with cerebral palsy. Phys Ther 2013; 93: 393-400.
[7] Russell DJ, Rosenbaum PL, Cadman DT, Gowland C, Hardy S and Jarvis S. The gross motor function measure: a means to evaluate the effects of physical therapy. Dev Med Child Neurol 1989; 31: 341-352.
[8] Ataç T, Özal C and Kerem Günel M. Reliability and validity of the Turkish version of the gross motor function measurement (GMFM-88 and GMFM-66) in children with cerebral palsy. Children (Basel) 2024; 11: 1076.
[9] Talgeri AJ, Nayak A, Karnad SD, Jain P, Tedla JS, Reddy RS and Sangadala DR. Effect of trunk targeted interventions on functional outcomes in children with cerebral palsy- a systematic review. Dev Neurorehabil 2023; 26: 193-205.
[10] Lim MS, Yoo BC and Lim HW. The effects of trunk intervention on gross motor function,

balance, and spasticity in cerebral palsy: a systematic review and meta-analysis. Medicina (Kaunas) 2025; 61: 1324.

[11] Mohamed N, Ibrahim MB, El-Agamy OA, Aldhahi MI and Elsebahy SY. Effects of core stability training on balance, standing, and gait in children with mild cerebral palsy: a randomized controlled trial. Healthcare (Basel) 2025; 13: 1296.

[12] Reddy S and Balaji GK. Dynamic surface exercise training in improving trunk control and gross motor functions among children with quadriplegic cerebral palsy: a single center, randomized controlled trial. J Pediatr Neurosci 2020; 15: 214-219.

[13] Gurusamy L, Balaji G and Agrahara S. A multicenter, double blind, randomized controlled trial of functional strength training on gross motor function among children with spastic diplegic cerebral palsy. Physiother Q 2022; 30: 52-58.

[14] Adıguzel H and Elbasan B. Effects of modified Pilates on trunk, postural control, gait and balance in children with cerebral palsy: a single-blinded randomized controlled study. Acta Neurol Belg 2022; 122: 903-914.

[15] Cortés-Pérez I, Castillo-Pintor MLÁ, Barrionuevo-Berzosa R, Piñar-Lara M, Obrero-Gaitán E and García-López H. Dual-task training interventions for cerebral palsy: a systematic review and meta-analysis of effects on postural balance and walking speed. Medicina (Kaunas) 2025; 61: 1415.

[16] Gagnat Y, Brændvik SM and Roeleveld K. Surface electromyography normalization affects the interpretation of muscle activity and coactivation in children with cerebral palsy during walking. Front Neurol 2020; 11: 202.

[17] Schmidt BG, Gerzson LR and de Almeida CS. The use of surface electromyography as a measure of physiotherapy outcomes in children with cerebral palsy: a systematic review. J Hum Growth Dev 2020; 30: 216-226.

[18] Viruega H, Gaillard I, Briatte L and Gaviria M. Inter-day reliability and changes of surface electromyography on two postural muscles throughout 12 weeks of hippotherapy in patients with cerebral palsy: a pilot study. Brain Sci 2020; 10: 281.

[19] Daly C, Lafferty E, Joyce M and Malone A. Determining the most effective exercise for gluteal muscle activation in children with cerebral palsy using surface electromyography. Gait Posture 2019; 70: 270-274.

[20] Bell KL and Samson-Fang L. Nutritional management of children with cerebral palsy. Eur J Clin Nutr 2013; 67 Suppl 2: S13-S16.

[21] Hamid Namaganda L, Andrews C, Wabwire-Mangen F, Peterson S, Forssberg H and Kakooza-Mwesige A. Nutritional status and growth of children and adolescents with and without cerebral palsy in eastern Uganda: a longitudinal comparative analysis. PLOS Glob Public Health 2023; 3: e0001241.

[22] Jahan I, Sultana R, Afroz M, Muhit M, Badawi N and Khandaker G. Dietary intake, feeding pattern, and nutritional status of children with cerebral palsy in rural Bangladesh. Nutrients 2023; 15: 4209.

[23] Chamova R, Nikolova S, Toneva A, Braykova R, Hadzhieva S, Bocheva Y and Pancheva R. Iron deficiency prevalence in Bulgarian children with cerebral palsy and autism: a call for nutritional interventions to support development. Nutrients 2025; 17: 1969.

[24] Jahan I, Sultana R, Muhit M, Akbar D, Karim T, Al Imam MH, Das MC, Smithers-Sheedy H, McIntyre S, Badawi N and Khandaker G. Nutrition interventions for children with cerebral palsy in low- and middle-income countries: a scoping review. Nutrients 2022; 14: 1211.

[25] Zhao Y, He L, Peng T, Liu L, Zhou H, Xu Y, Yang X, Huang Y, Chen Z, Xu Y, Li J, Hou X, Tang H and Xu K. Nutritional status and function after high-calorie formula versus Chinese food intervention in undernourished children with cerebral palsy. Front Nutr 2022; 9: 960763.

[26] Leal-Martínez F, Franco D, Peña-Ruiz A, Castro-Silva F, Escudero-Espinosa AA, Rolón-Lacarrier OG, López-Alarcón M, De León X, Linares-Eslava M and Ibarra A. Effect of a nutritional support system (diet and supplements) for improving gross motor function in cerebral palsy: an exploratory randomized controlled clinical trial. Foods 2020; 9: 1449.

[27] Rebelo F, Mansur IR, Miglioli TC, Meio MDB and Junior SCG. Dietary and nutritional interventions in children with cerebral palsy: a systematic literature review. PLoS One 2022; 17: e0271993.

[28] Zhao J, Qiu Y and Wang H. Nutritional risk screening and nutritional assessment for children with cerebral palsy: a review of the current research status and future directions. Clin Nutr ESPEN 2025; 65: 382-389.

[29] Chen CL, Shen IH, Chen CY, Wu CY, Liu WY and Chung CY. Validity, responsiveness, minimal detectable change, and minimal clinically important change of pediatric balance scale in children with cerebral palsy. Res Dev Disabil 2013; 34: 916-922.

[30] Franjoine MR, Gunther JS and Taylor MJ. Pediatric balance scale: a modified version of the berg balance scale for the school-age child with mild to moderate motor impairment. Pediatr Phys Ther 2003; 15: 114-128.

[31] World Health Organization Multicentre Growth Reference Study Group. WHO Child Growth Standards: length/height-for-age, weight-for-age, weight-for-length, weight-for-height and body mass index-for-age: methods and development. Geneva: World Health Organization; 2006.

[32] de Onis M, Onyango AW, Borghi E, Siyam A, Nishida C and Siekmann J. Development of a WHO growth reference for school-aged children and adolescents. Bull World Health Organ 2007; 85: 660-667.