

Effects of Home-Based Gait Training with Exoskeleton Robot on Lower Limb Motor Function and Hip Stability in Children with Type 2 Spinal Muscular Atrophy: A Single-Arm Self-Controlled Trial

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Abstract

Background

In children with type 2 spinal muscular atrophy (SMA), progressive muscle weakness and secondary musculoskeletal complications impose substantial functional limitations. Conventional rehabilitation frequently fails to deliver the high-intensity, weight-bearing gait training required to improve motor function and hip stability. To our knowledge, this is the first systematic evaluation of a 12-week home-based exoskeleton program in this population. We therefore aimed to examine the effects of a pediatric exoskeleton robot (KIDGO) on lower-limb motor function and hip stability in children with type 2 SMA.

Methods

We conducted a single-arm, prospective, self-controlled trial. Eight children (mean age 6.4 ± 2.2 years, range 4–10) completed a 12-week home-based robot-assisted gait training regimen (three 60-min sessions per week). Blinded assessors evaluated outcomes at baseline (V1), mid-intervention (V2, after 18 sessions), and post-intervention (V3, after 36 sessions).

Results

All participants completed the protocol (100% adherence) with no serious adverse events. Wee-FIM total score improved significantly (71.6 ± 16.1 to 75.1 ± 15.9 ; mean change $+3.5$; $^{*}t^{*} = -2.667$; $P = 0.032$). HFMSE and RULM scores showed non-significant marginal gains. Strength increased significantly in six lower-limb muscle groups (all $P < 0.05$). Hip or knee range of motion did not change significantly; however, left ankle ROM decreased notably ($102.5^{\circ} \pm 21.1^{\circ}$ to $94.5^{\circ} \pm 22.7^{\circ}$; $^{*}t^{*} = 3.813$; $P = 0.005$). Right migration percentage showed a marginally significant reduction ($29.9 \pm 10.5\%$ to $28.2 \pm 10.1\%$; $^{*}t^{*} = 2.231$; $P = 0.061$), while left MP declined non-significantly.

Conclusions

Home-based exoskeleton gait training appears safe and feasible for children with type 2 SMA, yielding significant gains in daily living activities and specific muscle strength. Positive trends in gross motor function and hip stability, though not statistically significant, warrant further investigation. These findings support the integration of exoskeleton technology into comprehensive SMA rehabilitation. Larger randomized controlled trials with extended follow-up are needed to confirm long-term efficacy and to refine patient-specific training protocols.

Trial registration

The trial has been registered at the Chinese Clinical Trial Registry (ChiCTR) and is currently awaiting review.

Introduction

Spinal muscular atrophy (SMA) is an autosomal recessive neuromuscular disorder caused by mutations in the survival motor neuron 1 (*SMN1*) gene. The key pathological characteristic is progressive degeneration of anterior horn cells in the spinal cord, resulting in diffuse muscle weakness and atrophy [1]. Children with type 2 SMA typically present between 6 and 18 months of age. Although they can achieve independent sitting, they are unable to walk without assistance and remain wheelchair-dependent throughout life [2]. Over time, these children experience not only progressive muscle weakness but also a high risk of secondary musculoskeletal complications, including joint contractures, scoliosis, and hip subluxation or dislocation. A recent multicenter study in China reported high prevalence rates of these complications—scoliosis in 59%, joint contractures in 62%, and hip dislocation in 21% of children with SMA—with older age significantly associated with disease progression [3]. These complications markedly impair functional capacity and independence, reduce quality of life, and impose substantial burdens on families and healthcare systems.

The introduction of disease-modifying therapies (DMTs), such as nusinersen and risdiplam, has revolutionized the management of spinal muscular atrophy (SMA) by slowing disease progression and extending survival [4]. However, these agents exert limited effects on reversing established muscle atrophy, joint contractures, or skeletal deformities. Large-scale studies have demonstrated that musculoskeletal complications may continue to progress despite nusinersen administration, underscoring the importance of integrating active rehabilitation with pharmacological treatment [3]. Conventional physical therapy and orthotic interventions can preserve range of motion to some extent but are inadequate for delivering high-intensity, repetitive, weight-bearing gait training—an approach likely critical for inducing neuroplasticity and achieving functional improvement [5]. This limitation highlights the need for innovative strategies that enable targeted, intensive locomotor training.

Robot-assisted gait training (RAGT) using exoskeletons has emerged as a promising approach. These wearable devices provide controlled mechanical assistance, enabling users to stand, transfer, and walk. In adults with neurological conditions, RAGT improves gait symmetry, muscle strength, and cardiopulmonary fitness, while reducing disuse-related complications [6]. Translating this technology to pediatric populations—especially those with neuromuscular disorders—poses distinct challenges. Systematic reviews have confirmed the safety of RAGT in cerebral palsy, but robust evidence in SMA remains sparse, with only a few case reports suggesting improved activity tolerance and functional gains in home settings [7, 8].

Several mechanisms might explain the potential benefits of exoskeleton use in type 2 SMA. Controlled weight-bearing may promote bone mineralization and counter disuse osteoporosis. Repetitive, physiologically patterned stepping could activate residual neural circuits and facilitate neuroplasticity,

thereby augmenting muscle force. Moreover, exoskeleton-mediated loading may alter hip joint biomechanics, reducing aberrant shear forces and fostering acetabular development, which could enhance stability. Beyond lower-limb systems, analogous upper-limb wearable robots are being developed, reflecting a broader goal of comprehensive functional restoration [9]. Nevertheless, systematic studies quantifying these effects—particularly on hip stability—are lacking.

To address this gap, we designed a single-arm prospective self-controlled trial to evaluate the KIDGO pediatric exoskeleton's impact on lower-limb motor function and hip stability in children with type 2 SMA. Unlike previous reports, we used a multidimensional set of objective measures: dynamometry, goniometry, standardized functional scales (HFMSE, Wee-FIM), and radiographic hip morphology (Reimers index). All participants adhered to a rigorous 12-week protocol (standing, sit-to-stand, active-assisted walking, and balance exercises). Our primary hypothesis was that 12 weeks of KIDGO training would significantly improve muscle strength, functional independence, and hip stability, while remaining safe and well tolerated.

We hypothesized that 12 weeks of KIDGO training would significantly improve lower limb muscle strength, functional independence (as measured by Wee-FIM and HFMSE), and reduce Reimers index in children with type 2 SMA, while remaining safe and well tolerated.

1.Methods

1.1 Study Design

This was a single-arm, prospective, self-controlled trial. The study protocol was approved by the Institutional Review Board of the Children's Hospital Affiliated to Shandong University (Approval No. SDFE-IRB/P-2025007). Written informed consent was obtained from the parents or legal guardians of all participants, and written assent was obtained from children aged 8 years and older.

Children with spinal muscular atrophy (SMA) type 2 who received treatment at our hospital between May and November 2025 were enrolled. The inclusion criteria were as follows: (1) age 3–14 years with genetically confirmed SMA type 2; (2) ability to maintain independent upright head and trunk posture, with or without orthotic assistance; (3) inability to ambulate 10 meters independently, requiring wheelchair use; (4) receipt of disease-modifying therapy (DMT) within the preceding 6 months; and (5) provision of signed informed consent. The exclusion criteria were: (1) body weight > 35 kg, femur length < 22 cm or > 38 cm, or tibia length < 21 cm or > 37 cm (incompatible with device size); (2) pre-existing hip dislocation (Reimer's migration percentage [MP] > 40%); (3) Cobb angle > 25° without orthotic support; (4) requirement for daytime non-invasive or invasive ventilatory support; (5) history of spinal or limb surgery within the past 6 months or planned surgery within the following 6 months; (6) severe dermatologic conditions or hypersensitivity to device attachment materials; and (7) inability to comprehend simple instructions or cooperate with training procedures.

1.2 Intervention

All participants completed 12 weeks of robot-assisted gait training (RAGT) using a pediatric exoskeleton (KIDGO personal exoskeleton). Device sizing was based on individual measurements of femur length, tibia length, and pelvic width. Training sessions were conducted three times per week, each lasting 60 minutes, for a total of 36 sessions. Each session comprised: non-weight-bearing standing (10 min), sit-to-stand transitions (10 min), walking in automatic and active-assisted modes (10 min each, total 20 min), trunk rotation during ambulation (10 min), walking while performing ball-handling tasks (5 min), and static balance training (5 min). A 15-minute lower limb stretching routine was performed before each session and was not included in the recorded training duration. All sessions were delivered by the same therapeutic team, with physician supervision during the initial session to ensure safety.

Typical training scenarios are illustrated in Fig. 1.

a b

Figure 1. The KIDGO pediatric exoskeleton and home-based training scenario. (a) A child with type 2 SMA wearing the KIDGO exoskeleton. The device was sized according to individual femur length, tibia length, and pelvic width. (b) Home-based training environment, showing assisted standing and walking practice in a living-room setting.

1.3 Outcome Measures

Primary Outcomes:

Muscle Strength: Maximal isometric strength (in Newtons) of bilateral hip flexors/extensors, knee flexors/extensors, and ankle dorsiflexors/plantarflexors was assessed using a handheld dynamometer (HHD, Model 01165, Lafayette Instrument Company). A blinded physical therapist (not involved in the intervention) performed all assessments at baseline (V1), mid-intervention (V2, one week after completion of 18 sessions), and post-intervention (V3, one week after completion of 36 sessions).

Range of Motion (ROM): Active or passive ROM (in degrees) of bilateral hip, knee, and ankle joints in the sagittal plane was measured using a standard goniometer by the same blinded assessor.

Hammersmith Functional Motor Scale Expanded (HFMSE): A validated instrument for evaluating gross motor function, with total scores ranging from 0 to 66 (higher scores indicating better motor performance). Assessments were conducted at V1 and V3.

Functional Independence Measure for Children (Wee-FIM): A standardized scale assessing functional independence in activities of daily living across six domains—self-care, sphincter control, transfers, locomotion, communication, and social cognition. Total scores range from 18 to 126, with higher values indicating greater independence. Evaluations were performed at V1 and V3.

Reimers Migration Percentage (MP): The proportion of the femoral head located lateral to the outer margin of the acetabulum was calculated from anteroposterior pelvic radiographs to assess hip joint stability. An $MP \leq 25\%$ was defined as normal, 25%–33% indicated hip instability, 33%–40% represented a

high risk of subluxation, and > 40% indicated established subluxation [10]. Radiographs were obtained at V1 and V3 and independently interpreted by a blinded radiologist.

Secondary Outcomes:

Adherence: Number of completed training sessions and total training duration.

Revised Upper Limb Module (RULM): A standardized measure of upper limb function specifically designed for individuals with SMA, with scores ranging from 0 to 37 (higher scores indicating better upper limb function). RULM was assessed at V1 and V3 as an exploratory secondary outcome to monitor any potential indirect effects of lower-limb training on upper limb function.

Safety: Incidence of all adverse events, including skin integrity compromise, joint pain, and falls.

1.4 Statistical Analysis

Data were analyzed using SPSS version 27.0. Continuous variables are presented as mean $\pm$ standard deviation (SD). The normality of differences between pre- and post-intervention values was assessed using the Shapiro–Wilk test. Paired t-tests were applied for normally distributed data; otherwise, the Wilcoxon signed-rank test was used. The significance level was set at $\alpha = 0.05$ (two-tailed). P-values between 0.05 and 0.08 were considered marginally significant and interpreted descriptively.

2. Results

2.1 Participant Characteristics and Adherence

Eight children with spinal muscular atrophy (SMA) type 2 (5 males, 3 females; mean age 6.4 ± 2.2 years, range 4–10 years) were enrolled. All participants completed the 36 prescribed training sessions, achieving 100% adherence. No device-related serious adverse events were reported. Two children experienced mild knee discomfort during initial sessions, which resolved after strap adjustment. Baseline characteristics are summarized in Table 1.

Table 1
Baseline Characteristics of Study Participants

ID	Type	Age (y)	Height (cm)	Weight (kg)	SMN2 Copies	Medication
101	2	7	139	28	3	Nusinersen
103	2	8	120	16	3	Nusinersen
104	2	10	130	30	2	Risdiplam
105	2	7	122	30	2	Risdiplam
108	2	4	90	12.5	3	Nusinersen+Risdiplam
109	2	5	110	20.5	3	Zolgensma
110	2	5	110	16.2	3	Nusinersen+Risdiplam
113	2	5	103	12	3	Nusinersen
Mean ± SD		6.4 ± 2.2	115.5 ± 16.6	20.7 ± 8.4		

2.2 Functional Scale Scores

Table 2
Comparison of Functional Scale Scores Pre- and Post-Intervention (Mean ± SD)

Outcome	V1 (Baseline)	V3 (Post-intervention)	Change (V3-V1)	Statistic	P-value
Wee-FIM	71.6 ± 16.1	75.1 ± 15.9	3.5 ± 4.1	t=-2.667	0.032*
HFMSE	37.6 ± 7.4	39.8 ± 5.8	2.2 ± 5.6	z=-1.782	0.075
RULM	27.7 ± 5.1	28.9 ± 4.8	1.2 ± 2.5	z=-1.867	0.062
Note: *P < 0.05.					

2.3 Hip Stability (Reimers Index)

A trend toward improved hip stability was observed post-intervention. The right migration percentage (MP) decreased from 29.9 ± 10.5% to 28.2 ± 10.1% (paired t-test, t = 2.231, P = 0.061, marginally significant). The left MP decreased from 27.1 ± 9.1% to 25.1 ± 8.8% (t = 1.417, P = 0.194) (Table 3, Fig. 2).

Table 3
Comparison of Reimers Index Pre- and Post-Intervention (Mean ± SD)

Side	V1 (%)	V3 (%)	Change (V3-V1, %)	Statistic	P-value
Right	29.9 ± 10.5	28.2 ± 10.1	-1.7 ± 2.4	t = 2.231	0.061
Left	27.1 ± 9.1	25.1 ± 8.8	-2.0 ± 4.5	t = 1.417	0.194
Note: Marginally significant P-value (0.05 ≤ P < 0.08).					

2.4 Muscle Strength

Significant improvements were observed in multiple lower limb muscle groups post-intervention. Strength in right hip flexion, right knee flexion, right ankle dorsiflexion, left hip flexion, left knee extension, and left ankle dorsiflexion increased significantly ($P < 0.05$). Changes in right hip extension, right ankle plantarflexion, left hip extension, left knee flexion, and left ankle plantarflexion were not statistically significant ($P > 0.05$) (Table 4).

Table 4
Comparison of Lower Limb Muscle Strength Pre- and Post-Intervention (Mean $\pm$ SD, Newtons)

Muscle Group (Side)	V1	V3	Change (V3-V1)	Statistic	P-value
Right Hip Flexion	2.5 $\pm$ 1.5	3.7 $\pm$ 1.8	1.2 $\pm$ 1.5	t=-2.588	0.037*
Right Hip Extension	3.6 $\pm$ 2.3	4.4 $\pm$ 2.4	0.8 $\pm$ 1.4	t=-1.836	0.099
Right Knee Flexion	1.9 $\pm$ 1.0	2.6 $\pm$ 1.3	0.7 $\pm$ 0.6	t=-3.774	0.008*
Right Knee Extension	1.6 $\pm$ 1.2	1.8 $\pm$ 1.8	0.2 $\pm$ 1.3	z=-0.734	0.463
Right Ankle Plantarflexion	3.1 $\pm$ 1.2	3.8 $\pm$ 1.7	0.7 $\pm$ 1.0	t=-2.181	0.066
Right Ankle Dorsiflexion	5.0 $\pm$ 3.3	7.6 $\pm$ 3.1	2.6 $\pm$ 3.2	t=-2.565	0.037*
Left Hip Flexion	2.5 $\pm$ 1.3	3.3 $\pm$ 1.0	0.8 $\pm$ 1.3	t=-1.955	0.036*
Left Hip Extension	3.9 $\pm$ 2.2	4.4 $\pm$ 2.1	0.5 $\pm$ 2.1	t=-0.778	0.456
Left Knee Flexion	2.9 $\pm$ 1.8	3.4 $\pm$ 1.6	0.5 $\pm$ 1.2	t=-1.336	0.213
Left Knee Extension	1.4 $\pm$ 1.0	1.8 $\pm$ 1.2	0.4 $\pm$ 0.4	z=-2.371	0.018*
Left Ankle Plantarflexion	2.8 $\pm$ 1.3	3.3 $\pm$ 1.1	0.5 $\pm$ 0.8	t=-1.968	0.084
Left Ankle Dorsiflexion	5.7 $\pm$ 3.3	9.0 $\pm$ 2.8	3.3 $\pm$ 3.9	t=-2.704	0.030*

Note: * $P < 0.05$.

2.5 Joint Range of Motion

No significant changes were observed in the bilateral hip or knee range of motion (ROM) ($P > 0.05$). However, a significant reduction in left ankle ROM was detected ($t = 3.813$, $P = 0.005$), decreasing from $102.5 \pm 21.1^\circ$ to $94.5 \pm 22.7^\circ$. A decreasing trend was also noted in right ankle ROM ($z = -1.826$, $P = 0.068$) (Table 5).

Table 5
Comparison of Lower Limb Range of Motion Pre- and Post-Intervention (Mean $\pm$ SD, degrees)

Joint (Side)	V1	V3	Change (V3-V1)	Statistic	P-value
Left Hip	154.3 $\pm$ 19.8	152.8 $\pm$ 10.3	-1.5 $\pm$ 4.1	t = 1.157	0.280
Right Hip	158.9 $\pm$ 12.9	157.5 $\pm$ 9.4	-1.4 $\pm$ 2.7	t = 1.624	0.143
Left Knee	146.5 $\pm$ 12.9	146.8 $\pm$ 9.8	0.3 $\pm$ 2.2	t = 0.420	0.685
Right Knee	146.0 $\pm$ 11.4	146.8 $\pm$ 9.6	0.8 $\pm$ 2.7	t = 0.935	0.377
Left Ankle	102.5 $\pm$ 21.1	94.5 $\pm$ 22.7	-8.0 $\pm$ 6.6	t = 3.813	0.005*
Right Ankle	104.8 $\pm$ 12.6	96.5 $\pm$ 11.7	-8.3 $\pm$ 13.2	z=-1.826	0.068

Note: *P < 0.05.

3. Discussion

This study represents, to our knowledge, the first systematic evaluation of a 12-week pediatric exoskeleton training program in children with type 2 spinal muscular atrophy (SMA). Overall, the intervention was safe and well tolerated, with all 8 participants completing the entire protocol. Regarding efficacy, significant improvements were observed in activities of daily living (as measured by the Wee-FIM) and in specific lower-limb muscle groups, while gross motor function (HFMSE) and radiographic hip parameters showed favorable trends that did not reach statistical significance. These findings not only support the feasibility of exoskeleton-assisted training in children with SMA but also provide a foundation for further research into its potential effects on neuromuscular performance and long-term musculoskeletal outcomes.

3.1 Impact on Daily Living Activities

We observed a notable improvement in Wee-FIM scores, particularly in the “transfers” and “locomotion” subscales—domains directly targeted by our training. This pattern suggests a capacity-enhancing effect: by compensating for impaired motor control, the exoskeleton enables children to perform functional tasks that would otherwise be unattainable, thereby promoting greater engagement in daily life [12]. The immediate mechanical support and balance assistance likely bolstered confidence, allowing children to rise from a chair or walk short distances with aid—actions that reduce caregiver dependency and enhance functional autonomy.

Interestingly, while Wee-FIM scores improved significantly, HFMSE scores—reflecting unassisted gross motor function—increased only marginally and not significantly. This dissociation underscores a key distinction: exoskeleton training may rapidly enhance functional capacity through assistive mechanisms, whereas genuine functional recovery (i.e., independent motor improvement) may require longer or more

intensive training to induce detectable neuroplastic changes [13]. Clinically, this distinction is meaningful—even without measurable gains in unsupported motor function, improvements in daily independence offer tangible benefits for both children and their families.

3.2 Effects on Muscle Strength and Hip Stability

Significant strength gains emerged in several lower-limb muscle groups—especially hip flexors, knee flexors, and ankle dorsiflexors—all crucial for gait. These improvements likely arise from the high-repetition, task-specific nature of exoskeleton training, wherein precisely timed assistance or resistance promotes active muscle engagement during critical phases of the gait cycle [14]. This interpretation aligns with findings from cerebral palsy studies that used similar intermittent assistance/resistance paradigms [15].

In contrast, strength increases in extensor groups (e.g., left knee extensors) were less pronounced, possibly reflecting SMA's pathophysiology—antigravity muscles are typically more severely affected and may demand greater mechanical loading to respond. Additionally, the exoskeleton's supportive role during stance might reduce the demand for active antigravity contraction, limiting adaptive strengthening of extensors [16].

Although the reduction in Reimers migration percentage did not reach overall statistical significance, the downward trend at the individual level—especially in several children—merits attention. Hip instability in SMA stems from muscular imbalances around the joint, leading to progressive structural deterioration over time [3]. Weight-bearing stimulation from the exoskeleton may promote hip stabilization via axial loading, which is known to foster acetabular development and improve femoral head coverage. The pronounced bilateral MP reduction observed in one child (ID 109) suggests possible responder subgroups. Overall, these observations imply that exoskeleton training might help preserve hip integrity, potentially through optimized dynamic biomechanics rather than mere soft-tissue stretching.

3.3 Effects on Joint Range of Motion

The unexpected decrease in ankle ROM highlights the distinct musculoskeletal pathophysiology of SMA. Unlike spastic conditions (e.g., cerebral palsy), where short-term stretch can improve ROM, SMA involves progressive muscle fiber atrophy, fatty infiltration, and connective tissue proliferation, which reduce tissue extensibility and render ROM less responsive to short-term mechanical interventions [15, 16].

Several factors could account for the observed ankle ROM reduction. First, our training emphasized plantarflexor strengthening, with relatively smaller gains in dorsiflexor strength, potentially creating an imbalance that favors a plantarflexed ankle posture. Second, the exoskeleton may provide limited dorsiflexion assistance; if the device does not accommodate the child's natural ankle kinematics, compensatory gait patterns might develop, restricting distal motion or even predisposing to contractures [17]. Finally, children may adopt compensatory strategies to avoid full excursion through the available range. Clinically, this finding carries important implications: clinicians should closely monitor ankle ROM during exoskeleton use, incorporating passive stretching, active dorsiflexion exercises, and careful

device fitting into standard practice. It also underscores the need for future device design to incorporate enhanced dorsiflexion assistance and control.

3.4 Study Limitations

We acknowledge several limitations. The single-arm design with a small sample size provides preliminary safety and feasibility data, but the absence of a control group precludes definitive attribution of observed changes solely to the intervention; some strength gains could be partially influenced by concurrent disease-modifying therapies or natural development. Second, 12 weeks may be insufficient to detect meaningful structural changes in hip stability; radiographic parameters like MP typically require longer follow-up. Third, we did not assess the independent contributions of different training modes (automatic vs. active-assisted), limiting our ability to define optimal parameters. Finally, although outcome assessors were blinded, participants were not, so expectancy effects cannot be completely excluded. Despite these constraints, our findings offer a robust foundation for designing larger randomized trials.

4. Conclusion

This study provides the first systematic evaluation of pediatric exoskeleton training in type 2 SMA. Our results demonstrate that a 12-week home-based program is safe, feasible, and well tolerated, yielding significant improvements in daily living activities and specific lower-limb muscle strength, along with promising trends in hip stability. These findings advocate for incorporating exoskeleton-assisted gait training into comprehensive SMA care. Future large-scale, randomized controlled studies with extended follow-up are essential to confirm long-term benefits on motor function and hip development, and to establish individualized training protocols that maximize clinical efficacy.

Declarations

Ethics approval and consent to participate

The Institutional Review Board of the Children's Hospital Affiliated to Shandong University approved this study (Approval No. SDFE-IRB/P-2025007). Parents or legal guardians of all participants gave written informed consent, and children aged 8 years and older gave written assent.

Consent for publication

Not applicable.

Availability of data and materials

The datasets generated and/or analyzed during the current study are not publicly available due to patient privacy and ethical restrictions but are available from the corresponding author on reasonable request.

Competing interests

MQ, TW, and HY are employees of Hangzhou RoboCT Technology Development Co., Ltd, the manufacturer of the KIDGO exoskeleton used in this study. The remaining authors declare that they have no competing interests.

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Authors' contributions

HZ, XG, WC, and YH contributed to the study conception and design. HZ, XG, and WC performed data collection and intervention delivery. MY performed radiographic assessments. GW and FW contributed to patient advocacy and funding support. MQ, TW, and HY contributed to exoskeleton device provision and technical support. HZ,YY,YC,and JL performed the statistical analysis and drafted the manuscript. YH supervised the study and critically revised the manuscript. All authors read and approved the final manuscript.

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Use of artificial intelligence

During the preparation of this manuscript, the authors used artificial intelligence tools (including large language models) for language polishing, grammar correction, and structural organisation. These tools were used to improve the clarity and readability of the text, not to generate novel scientific content, data, or interpretations. The authors reviewed, verified, and approved all AI-assisted outputs and take full responsibility for the accuracy and integrity of the final manuscript.

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Figures



Figure 1

The KIDGO pediatric exoskeleton and home-based training scenario. (a) A child with type 2 SMA wearing the KIDGO exoskeleton. The device was sized according to individual femur length, tibia length, and pelvic width. (b) Home-based training environment, showing assisted standing and walking practice in a living-room setting.

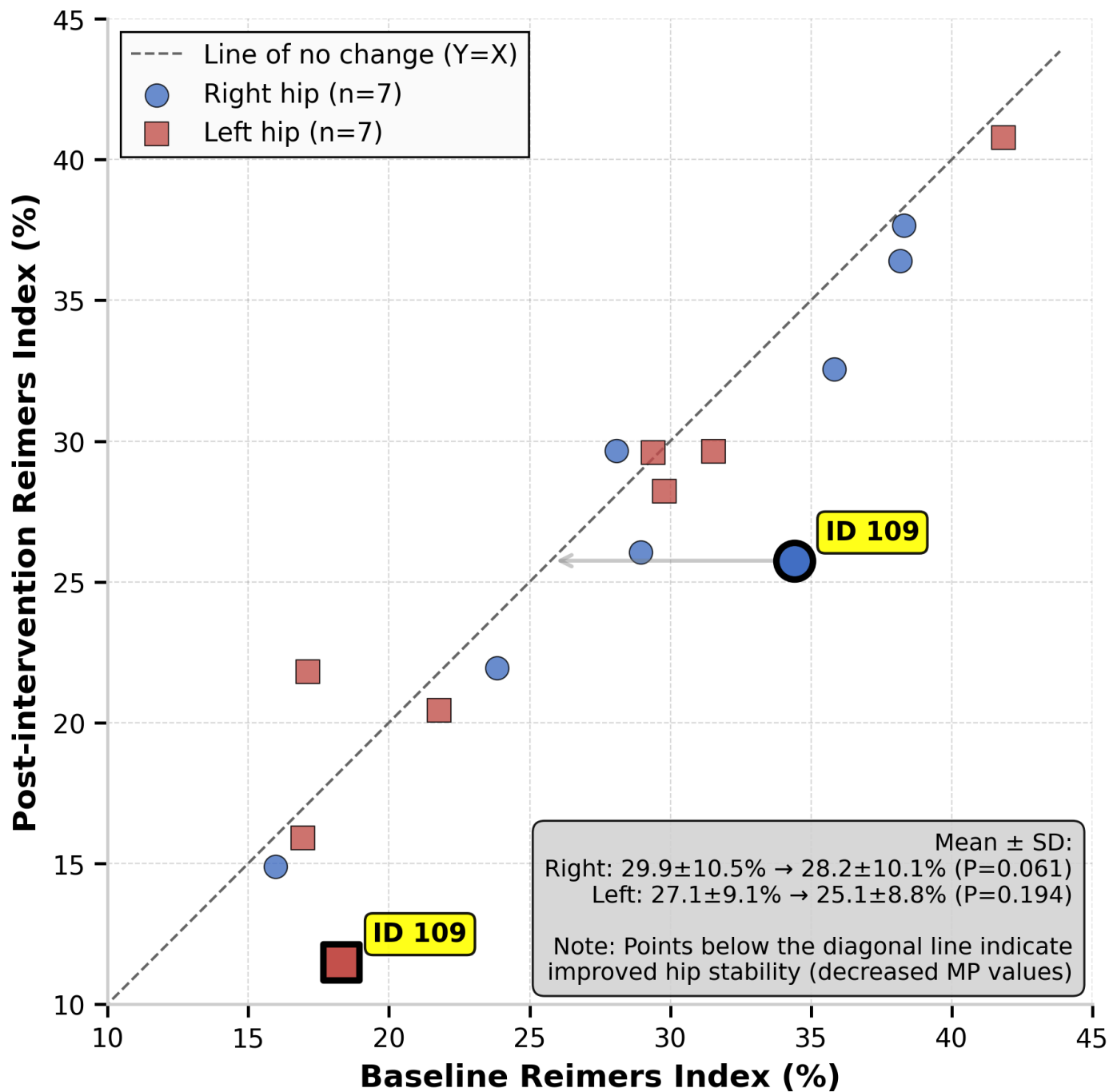


Figure 2

Individual Changes in Reimers Index Pre- and Post-Intervention