

The Effects of Stretching, Strengthening and Combined Interventions on Lower-Limb Spasticity in Spastic Cerebral Palsy: A Systematic Review

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ABSTRACT

Background: Spastic cerebral palsy (CP) is a common childhood neurological condition that results in abnormal muscle tone, motor dysfunction, and gait impairments. While stretching is widely used to reduce muscle stiffness, strengthening exercises are increasingly incorporated to improve functional mobility. Concerns remain, however, regarding whether strengthening may increase spasticity. **Method:** This review followed the Preferred Reporting Items for Systematic Reviews and Meta-Analyses (PRISMA) guidelines. A comprehensive search of studies published between 2004 and 2024 was conducted across major databases. Eligible studies included those evaluating stretching, strengthening, or combined interventions targeting lower-limb spasticity in individuals with spastic CP. Risk of bias was assessed using the Cochrane Risk-of-Bias tool (ROB-2). **Results:** Twelve studies met the inclusion criteria. Intervention categories comprised stretching alone (n = 2), strengthening alone (n = 2), and combined stretching–strengthening programmes (n = 8). Findings indicated that stretching alone and strengthening alone do not consistently reduce lower-limb spasticity, although both may help preserve muscle and joint properties. Combined exercise programmes demonstrated mixed outcomes: some studies reported improvements in tendon stiffness, fascicle length, and clinical spasticity scores, while others showed no significant effects. Despite inconsistent spasticity outcomes, several studies noted functional gains, including better gait performance, enhanced muscle morphology, and improved movement efficiency. **Conclusion:** Overall, the evidence suggests that while combined interventions may offer selective benefits, reductions in spasticity are not uniformly observed. Current evidence does not support stretching, strengthening, or combined exercise programmes as consistently effective in reducing lower-limb spasticity in spastic CP, although functional improvements are frequently reported. Future research should prioritise spasticity as a primary outcome, standardise intervention parameters, and incorporate larger, methodologically robust samples to inform clinical practice.

Keywords:

Spastic cerebral palsy; stretching exercises; strengthening exercises; physiotherapy; lower-limb rehabilitation

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INTRODUCTION

Cerebral palsy (CP) is one of the most frequently encountered physical disabilities in children. It is defined as a permanent and non-progressive disorder of movement and posture caused by abnormalities in the developing brain (Sadowska et al., 2020). CP leads to limitations in mobility and daily living activities, including walking, dressing, and self-care (Hallman-Cooper & Cabrero, 2024). In Malaysia, CP affects an estimated 2–5 children per 1,000 births, of whom about 65% present with spastic subtype (Sundaresan et al., 2022; Azzimawati, 2017). Spastic CP is characterised by abnormal muscle tone, hyperreflexia, and stiffness of major lower-limb muscles, including the gastrocnemius-soleus complex, hamstrings, adductors and psoas (Bar-On et al., 2015), which can contribute to gait abnormalities and difficulty performing daily tasks.

Spasticity may lead to secondary musculoskeletal complications such as pain, contractures, and joint subluxations, further reducing independence and quality of life. Management strategies include physiotherapy, pharmacological interventions (e.g., botulinum toxin), and surgical options such as selective dorsal rhizotomy (Pavone et al., 2016; Rana et al., 2017). While pharmacological and surgical methods have established benefits, their invasive nature and costs make physiotherapy-based interventions an essential component of long-term management (Das & Ganesh, 2019).

Stretching is commonly used to preserve or increase range of motion and reduce muscle tightness (Wiar et al., 2008), whereas strengthening addresses muscle weakness, improves stability, and supports functional mobility (Shin et al., 2016). However, questions remain regarding whether strengthening exercises may

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worsen spasticity. Understanding the combined effects of stretching and strengthening is therefore essential for developing effective rehabilitation programmes. The prevalence of spastic CP has shown a declining trend in high-income countries, but the trends remain uncertain in low- and middle-income countries (Villamor, 2022; McIntyre et al., 2022). Given the persistent burden of spasticity and its impact on activities of daily living (Hallman-Cooper & Cabrero, 2024), this systematic review aimed to critically evaluate and synthesise the evidence regarding the efficacy of stretching, strengthening, and their combination in reducing lower-limb spasticity in individuals with spastic CP.

METHODS

This systematic review was conducted following PRISMA guidelines (Page et al., 2021). The PICOS framework was used to guide the search and selection process. Studies were eligible if they examined stretching, strengthening, or combined interventions in paediatric or adolescent spastic CP and included outcome measures related to lower-limb muscle tone such as the Modified Ashworth Scale (MAS), Modified Tardieu Scale (MTS), Muscle-Tension Unit (MTU), tendon stiffness, or popliteal angle.

For databases like Google Scholar, ProQuest and Scopus which do not use MeSH terms, free-text keywords were utilised. The search terms used in these databases included the following combinations: "spastic cerebral palsy" AND "stretching" OR "range of motion" AND "spasticity" for the effectiveness of stretching exercises, "spastic cerebral palsy" AND "strengthening exercise*" OR "resistance exercise*" OR "resistance training" AND "spasticity" for strengthening exercises and "spastic cerebral palsy" AND "stretching" AND "strengthening exercise*" OR "resistance training" OR "resistance exercise*" for the effect of combined exercises.

Screening was completed in two phases: title/abstract screening and full-text review. A single reviewer performed initial screening, with supervisory consultation when uncertainties occurred. Studies published between 2004 and 2024 and written in English or Bahasa Malaysia were considered. The date range (2004–2024) was selected because strengthening interventions for paediatric CP began entering contemporary clinical research in the early 2000s, accompanied by increased use of biomechanical

and tendon-morphology measures relevant to spasticity outcomes. Exclusion criteria included animal studies, Botulinum toxin Type A (BTX-A) administration within six months, surgical interventions, or inadequate methodological rigour.

The ROB-2 tool assessed randomisation, intervention adherence, missing data, outcome measurement, and selective reporting (Sterne et al., 2019).

RESULTS

Study Selection

Database searches yielded a large initial pool of articles (Google Scholar: 10,020; PubMed: 7,962; ScienceDirect: 164,113; ProQuest: 596,610; MEDLINE: 662; Malaysian Theses Online: 0). Following duplicate removal ($n = 310,749$) and relevance screening, 356 articles underwent abstract review. Twelve studies ultimately met all inclusion criteria. Figure 1 in Appendix 1 demonstrates the PRISMA flow diagram for each stage of the study.

Assessment of Bias

Using ROB-2, nine articles demonstrated low risk of bias, and three studies showed some concerns. Two quasi-experimental studies (Wu et al., 2011; Zhao et al., 2011) were rated as high risk due to study design limitations while Ryan et al. (2020) showed some concern for not reporting the number of exact dropouts. Despite these issues, all studies were retained due to the limited number of trials addressing spasticity outcomes.

Study Characteristics

The 12 included studies comprised participants aged 4–19 years from Europe, Asia, and North America, with most classified within GMFCS Levels I–III. Outcome measures varied and included the MAS, MTS, MTU properties, tendon stiffness, popliteal angle, and other biomechanical indicators such as fascicle length and pennation angle. The studies differed in eligibility criteria, with several requiring participants to ambulate independently, and one study (Engsberg et al., 2006) specifying minimum passive dorsiflexion thresholds and the ability to perform active dorsiflexion and plantarflexion. Four studies evaluated stretching-only or strengthening-only interventions, while eight examined combined stretching and strengthening

programmes. Across all trials, no severe adverse events were reported. Table 1 in Appendix 2 summarises the characteristics of included studies.

Stretching Interventions

Two studies (Kruse et al., 2022; Kruse et al., 2023) assessed static versus proprioceptive neuromuscular facilitation (PNF) stretching. A single session of static stretching produced acute improvements in MTU length, although no significant changes were noted for muscle belly or Achilles tendon elongation. Over eight weeks, neither PNF nor static stretching resulted in significant changes in MTU resting length, strain, or muscle belly properties.

Strengthening Interventions

Two studies (Kruse et al., 2019; Yazici et al., 2023) examined strengthening alone. Kruse et al. (2019) observed improvements in MTU length and gastrocnemius morphology following progressive resistance training. Yazici et al. (2023) demonstrated improvements in dorsiflexor and plantar flexor spasticity using MTS scores, particularly in R1 and R2 values.

Combined Interventions

Eight studies evaluated combined stretching and strengthening. Findings were mixed:

- Significant improvements in tendon stiffness, fascicle length, or clinical spasticity were reported by Kalkman et al. (2019), Cho & Lee (2020), Ryan et al. (2020), and Wu et al. (2011) and Engsberg et al. (2006), who noted strength-related changes despite limited spasticity reduction.
- Non-significant findings were observed in Fosdahl et al. (2019), Lee et al. (2008), and Zhao et al. (2011).

Variability in outcomes likely reflects differences in study duration, exercise intensity, spasticity measurement methods and the use of closed kinetic chain (CKC) versus open kinetic chain (OKC) exercises.

DISCUSSION

Effectiveness of Stretching

Although stretching remains one of the most common physiotherapy strategies for managing spasticity,

evidence from recent studies suggests that its effects on neural components of tone are limited. As demonstrated in the work of Kruse et al. (2022, 2023), neither static nor proprioceptive neuromuscular facilitation stretching produced meaningful changes in MTU properties over an eight-week period. These findings reinforce earlier observations by Theis et al. (2015), who reported that improvements in muscle extensibility following stretching tend to be short-lived and predominantly mechanical rather than neurophysiological. This implies that stretching may temporarily lengthen soft tissues through viscoelastic deformation but does not substantially influence reflex hyperexcitability, which is the core driver of spasticity.

Collectively, the evidence indicates that stretching alone is better suited for maintaining joint range of motion and reducing the risk of contractures rather than modifying tone itself. This is consistent with clinical observations where stretching is often used as a preparatory technique prior to functional training rather than as a standalone intervention for reducing spasticity. However, the lack of measurable changes in muscle belly or tendon elongation in CP populations, despite regular stretching, suggests that long-standing spasticity and muscle morphology changes may limit the responsiveness of tissues to passive stretching. Therefore, stretching may still play a supportive role in rehabilitation but is unlikely to produce clinically meaningful reductions in spasticity when used independently.

Effectiveness of Strengthening

Strengthening interventions have traditionally raised concerns among clinicians due to the belief that increasing muscle force might exacerbate spasticity. However, evidence from Kruse et al. (2019) and Yazici et al. (2023) challenges this assumption. Both studies reported improvements in MTU length, gastrocnemius morphology, and MTS parameters without any indication of increased tone. These findings align with the neuromuscular rationale proposed by dos Santos et al. (2011), who emphasised that strengthening, particularly using CKC tasks can enhance motor unit recruitment, improve joint stability, and promote more efficient muscle activation patterns.

The observed improvements in MTU length and R1/R2 values suggest that strengthening may indirectly influence mechanical factors contributing to spasticity, such as stiffness and reduced tendon compliance.

Importantly, these changes occurred without provoking adverse reflex responses, indicating that strengthening, when appropriately dosed and supervised, is safe for individuals with spastic CP. CKC exercises may be particularly beneficial because they promote co-activation around joints, enhance proprioceptive input, and encourage functional movement patterns, all of which support better motor control.

The overall evidence therefore supports the inclusion of strengthening in rehabilitation programmes, not only for improving function but also for potentially modulating aspects of muscle behaviour associated with spasticity.

Effectiveness of Combined Interventions

The combined stretching-and-strengthening approach produced the most varied findings in this review, with some studies reporting favourable effects and others showing little or no change. Studies such as those by Kalkman et al. (2019), Cho and Lee (2020), Ryan et al. (2020), Wu et al. (2011), and Engsberg et al. (2006) reported improvements in tendon stiffness, fascicle length, strength parameters, or clinical spasticity scores, suggesting that integrating strengthening immediately after stretching may capitalise on increased muscle elongation and improved readiness for activation. In particular, Engsberg et al. (2006) demonstrated strength-related improvements despite limited reductions in spasticity, supporting the premise that combined programmes may enhance neuromuscular performance even when tone change is minimal. This sequential approach could theoretically reduce short-term passive resistance while reinforcing voluntary motor pathways through strengthening.

However, other studies such as those by Fosdahl et al. (2019), Lee et al. (2008), and Zhao et al. (2011) did not demonstrate significant changes in spasticity, despite similar combined protocols. Several factors may explain this heterogeneity. First, intervention intensity varied considerably across studies, ranging from low-resistance exercises to more structured progressive loading. Second, the duration of intervention was inconsistent, with some programmes lasting only four weeks—potentially too short to induce structural or neural adaptations. Third, outcome measures differed substantially; while some studies relied on clinical scales such as the MAS, others assessed biomechanical variables such as tendon stiffness or fascicle length,

making comparisons challenging.

Another important variable is the type of strengthening exercise. CKC-based programmes (e.g., those implemented by Cho and Lee, 2020; Ryan et al., 2020) appear more effective in influencing muscle–tendon behaviour and functional outcomes than mixed OKC/CKC programmes. CKC tasks tend to be more functional and involve greater sensory feedback, potentially contributing to improved reciprocal inhibition and reduced co-contraction mechanisms that may influence spasticity expression. The inconsistency across studies appears substantially driven by heterogeneity in outcome measures. Whereas some studies assessed spasticity using clinical scales such as MAS or MTS, others evaluated biomechanical properties such as tendon stiffness, fascicle length, or muscle–tendon unit behaviour. These outcomes capture different constructs and are not directly comparable, which limits synthesis and contributes to the lack of consensus observed in this review.

Overall, the evidence suggests that combined programmes may improve selected structural or functional outcomes but do not consistently reduce spasticity across all individuals. The variability highlights the need for clearer intervention parameters, including exercise intensity, duration, muscle groups targeted, and progression criteria. A further limitation relates to study selection. Screening and eligibility assessment were performed by a single reviewer with supervisory consultation during uncertainties. While common in student-led reviews, this approach may introduce selection bias and is less rigorous than dual independent screening recommended for systematic reviews.

CONCLUSION AND FUTURE DIRECTIONS

Overall, the available evidence does not show consistent reductions in lower-limb spasticity with stretching, strengthening, or even when the two are combined. Stretching appears helpful mainly for preserving joint mobility, strengthening may contribute to changes in muscle structure and control, and combined programmes can offer certain functional benefits. However, these improvements do not always translate into clear or sustained changes in spasticity itself. This inconsistency across studies suggests that stronger and more focused research is still needed before firm clinical guidance can be established.

Future work should place spasticity at the centre of

outcome measurement and adopt more uniform approaches to exercise intensity, duration, and progression. Larger, well-controlled studies would also help ensure that findings are more applicable to the wider CP population. In addition, clearer reporting of orthotic use is important to avoid confounding interpretations. Incorporating detailed biomechanical and neurophysiological assessments may further improve our understanding of how different exercise components influence spastic muscle responses over time.

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Declaration of Generative AI and AI-Assisted Technologies in the Writing Process

During the preparation of this work, the authors used ChatGPT (OpenAI) to assist with language refinement, organisation of content, and formatting according to journal guidelines. The authors subsequently reviewed, edited, and approved all content, and accept full responsibility for the final manuscript.

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Appendix 1

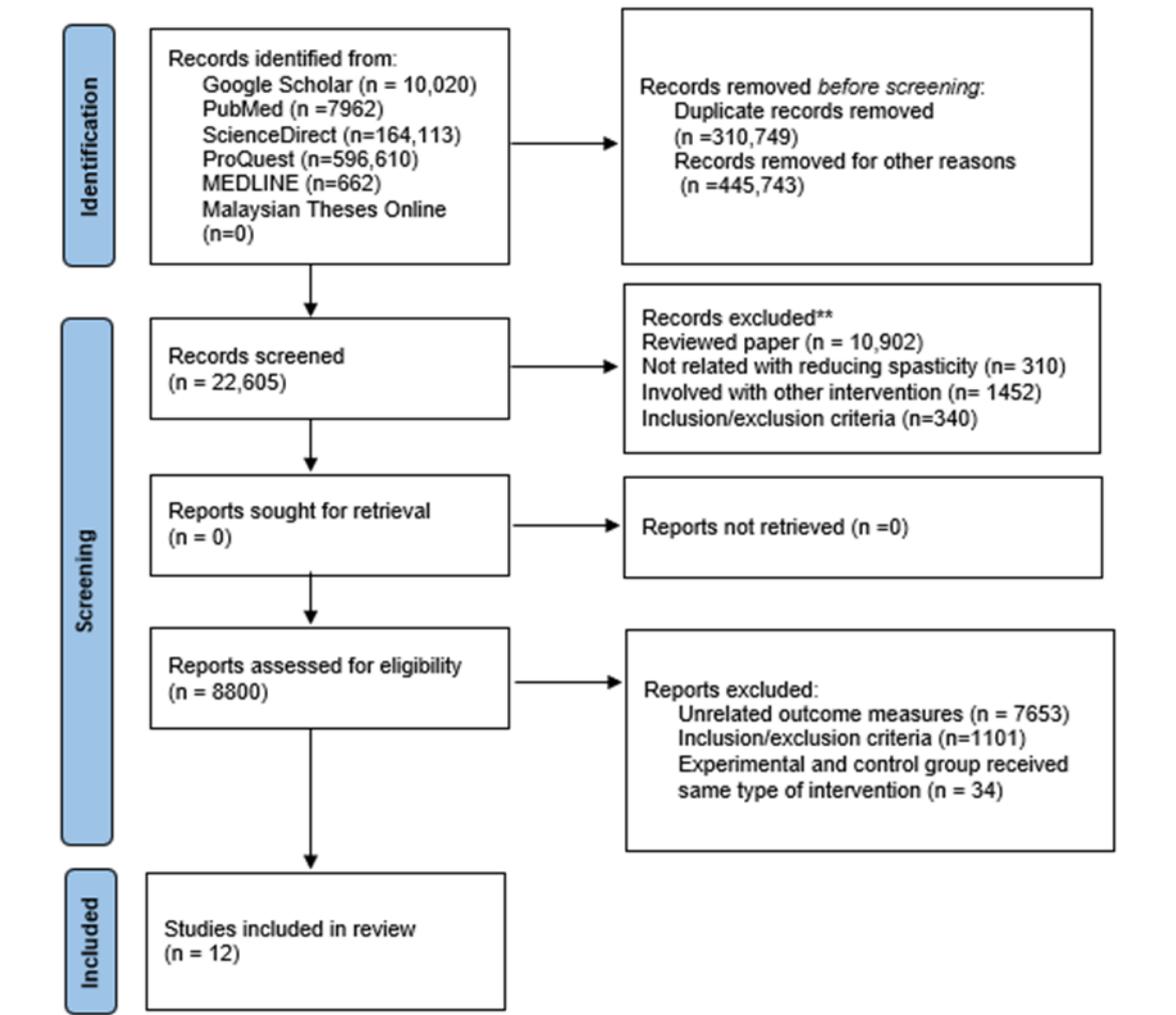


Figure 1 The PRISMA flow diagram for each stage of the study.

Appendix 2

Table 1 Characteristics of Included Studies

Author/ Country/ Title	Study design/ RoB	Participants/ Inclusion criteria/ Duration of study	Intervention	Outcome measure	Dropouts/Result
Kruse et al. (2022) Austria	RCT/Low	Participants (n=18), randomly divided into two groups	IG (n=8) Received: SS exercise: - In prone position with knees extended, therapist applied passive ankle DF to the available range (30s hold, 30s rest) -repeat in knees flexed position	Ankle ROM and maxDF Gastrocnemius MTU Muscle belly elongation AT elongation	Post-intervention No dropouts reported <u>MTU</u> <u>IG</u> Pre:18.3mm Post:20.9mm *p=0.05 <u>CG</u> Pre:20.3mm Post:18.5mm p=0.670
Acute Effects of Static and Proprioceptive Neuromuscular Facilitation Stretching of the Plantar Flexors on Ankle Range of Motion and Muscle-Tendon Behavior in Children with Spastic Cerebral Palsy—A Randomized Clinical Trial		Inclusion criteria: Age between 6-15years old Diagnosed with unilateral or bilateral spastic CP GMFCS level I-III Able to ambulate Able to follow instruction Had no severe contracture (defined as maxDF more or equal to 0° with knees extended) Exclusion criteria Received BTX injection 6 months prior Received any form of lower limb surgery 12 months prior Duration of study: 1 session	CG (n=10) Received: PNF: In prone position with knee extended, therapist applied passive ankle DF until tolerable range. Participants perform submaximal isometric contraction for 3-5s. Ankle then moved to greater DF and held for 25s. Rest for 30s. All exercises were repeated 10 repetitions on both legs.		<u>Muscle belly elongation</u> <u>IG</u> Pre:12.9mm Post:12.9mm p=0.465 <u>CG</u> Pre:13.6 Post:12.5 p=0.484 <u>AT elongation</u> <u>IG</u> Pre:5.4mm Post:8.0mm p=0.06 <u>CG</u> Pre:6.7mm Post:6.0mm p=0.272
Kruse et al. (2023) Austria	RCT/Low	Participants (n=24), randomly divided into two groups	IG (n=11) Received: SS exercise: - In prone position with knees extended, therapist applied passive ankle DF to the	Ankle ROM and maxDF Foot sole angle change Resting angle Peak externally applied torque Muscle activation Gastrocnemius MTU	Post-intervention After dropouts (n=20) IG (n=10) CG (n=10) <u>MTU</u> <u>(data in mean (SD))</u>

<p>stretching and static stretching do not affect muscle-tendon properties, muscle strength, and joint function in children with spastic cerebral palsy</p>	<p>GMFCS level I-III Able to ambulate Able to follow instruction Had no severe contracture (defined as maxDF more or equal to 0° with knees extended)</p> <p>Exclusion criteria Received BTX injection 6 months prior Received any form of lower limb surgery 12 months prior</p> <p>Duration of study: 8 weeks</p>	<p>available range (30s hold, 30s rest) -repeat in knees flexed position</p> <p>CG (n=13) Received: PNF: In prone position with knee extended, therapist applied passive ankle DF until tolerable range. Participants perform submaximal isometric contraction for 3-5s. Ankle then moved to greater DF and held for 25s. Rest for 30s.</p> <p>Exercises were repeated four times a week at home</p> <p>All exercises were repeated 10 repetitions both legs.</p>	<p>Muscle belly elongation Gastrocnemius muscle fascicle lengths and lengthening AT elongation</p>	<p><u>Resting length</u> <u>IG</u> Pre:0.94 (0.04) Post:0.95 (0.02) p=0.511 <u>CG</u> Pre:0.97 (0.02) Post:0.96(0.04) p=0.635</p> <p><u>MTU lengthening</u> <u>IG</u> Pre:0.05 (0.00) Post:0.05 (0.01) p=0.652 <u>CG</u> Pre:0.05 (0.01) Post:0.05(0.01) p=0.338</p>	
<p>Kruse et al. (2019) Austria The Effect of Functional Home-</p>	<p>RCT/Low</p>	<p>Participants (n=27) divided into two groups, Progressive Resistance Training (PRT) (IG) and High Intensity Circuit Training (HICT) (CG)</p>	<p>IG (n=12) Receive: Stretching exercises: Full body stretching for warm up (10 minutes)</p>	<p>Muscle and tendon morphological properties Ankle joint ROM Torque</p>	<p>Post-intervention After dropouts (n=22) IG (n=11) CG (n=11) Data in mean (SD)</p>

<p>Based Strength Training Programs on the Mechano-Morphological Properties of the Plantar Flexor Muscle-Tendon Unit in Children with Spastic Cerebral Palsy</p>	<p>Inclusion criteria: Age between 8 to 16 years old GMFCS level I and II Not having any contracture of PF (mx ankle DF >4° with knees extended) Able to walk independently Able to follow verbal instruction</p> <p>Exclusion criteria Forms other than spastic CP BTX injection in the past 6 months Previous surgery of ankle PF in the past 6 months Participants with epilepsy</p> <p>Duration of study: 24 weeks, 8 weeks of intervention, 16 weeks follow-up</p>	<p>and cooling down (5 minutes) Strengthening exercises: 1. sit to stand 2. heel raises 3. forward lunges 4. lateral step-up exercise 5. bridging exercise (10-12 repetitions for three sets with 2 minutes rest between sets) Resistance progressively increased with a weighted vest using 10 RM test Exercises were performed for 3 sessions per week for 8 weeks</p> <p>CG (n=15) Receive: Same treatment as IG group but with different load. Load was determined by the number of repetitions that could be completed within 30-second interval. No additional load was given. (Participants were told to perform as many repetitions as they could for 30 seconds, followed by 30 seconds rest in between)</p>	<p>Tendon mechanical and material properties</p>	<p><u>Muscle Tendon property</u></p> <p><u>1.MTU length</u> IG: Pre: 1.08 (0.03) Post: 1.10 (0.03) Follow-up:1.08 (0.02) p-value<0.05 for pre-post and post-follow-up CG: Pre:1.08 (0.03) Post: 1.08 (0.02) Follow-up:1.09 (0.01)</p> <p><u>2.AT length (normalised)</u> IG: Pre:0.57 (0.05) Post: 0.57 (0.05) Follow-up:0.54 (0.005) CG: Pre:0.55 (0.07) Post:0.54 (0.06) Follow-up: 0.54(0.06)</p> <p><u>3. GM belly length</u> IG Pre: 0.52 (0.06) Post: 0.53 (0.05) Follow-up: 0.53 (0.06) CG: Pre: 0.53 (0.06) Post: 0.54 (0.05) Follow-up:0.54 (0.06) p-value<0.05 for post-follow-up</p> <p><u>4.AT cross-sectional area (mm²)</u> IG: Pre:43.7 (7.9) Post:44.2 (9.9) Follow-up:45.8 (10.6) CG: Pre:51.5 (22.8) Post:50.0 (18.3) Follow-up: 48.8 (19.1)</p>
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Yazici et al. (2023) Turkey	RCT/Low	Participants (n=27), randomly divided into three groups, DF, PF and DF&PF exercises	<p>All group received functional exercise program targeting muscle of</p> <ol style="list-style-type: none"> 1.abdominal 2.back 3.hip extensor 4.abductors 5.quadriceps <p>Group A (n=9) DF exercise Received: 1.Walking up on a ramp 2.Walking down on ramp backwards 3.DF while sitting (knee in flexion) (intensity was increased by adjusting the degree of knee flexion)</p> <p>Group B (n=9) PF exercise Received: 1.Calf raises -difficulty was increased by increasing the degree of PF. At the beginning, movement was initiated from PF in shortened position. At the end of week 2, the exercise was conducted in foot flat on the surface followed by foot in DF.</p> <p>Group C (n=9) DF&PF Received: Both exercises given for GA and GB</p> <p>Exercises done 4 sessions per week (2 sessions for 45</p>	MTS PBS FRT TUG MVC	<p>Post-intervention After dropout (n=22) Group A (n=8) Group B (n=8) Group C (n=6)</p> <p>Result reported in IQR <u>MTS</u> <u>Affected side</u> <u>Group A</u> <u>Slow (R2) (°)</u> Pre: 10 (3.5/12.5) Post:15 (10/20) *p=0.015 <u>Rapid (R1) (°)</u> Pre: 0 (-1.5/7.5) Post:12 (7.5/17.5) *p=0.008 Difference Pre: 5 (0/10) Post: 0 (0/6.5) P=0.092</p> <p><u>Group B</u> <u>Slow (R2) (°)</u> Pre:10 (7/15) Post: 10 (10/20) p=0.197 <u>Rapid (R1) (°)</u> Pre: 5 (1/9.5) Post: 10 (5/15) *p=0.042 <u>Difference</u> Pre:6 (3/9.5) Post: 5 (0/7.5) p=0.260</p> <p><u>Group C</u> <u>Slow (R2) (°)</u> Pre: 10 (2.5/20) Post: 15 (9/20) p=0.104 <u>Rapid (R1) (°)</u> Pre: 0 (-7.5/7.5)</p>
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minutes at with a PT
and 2 sessions as
home under
supervision of
caregiver)

Post: 10 (9/15)
*p=0.017
Difference
Pre:10 (5/15.5)
Post: 5 (0/7.5)
*p=0.049

Less affected side

Group A

Slow (R2) (°)

Pre: 20 (11.5/20)

Post:20 (15/20)

p=0.465

Rapid (R1) (°)

Pre: 10 (10/20)

Post:20(15/20)

*p=0.039

Difference

Pre: 0 (0/7.5)

Post: 0 (0/0)

P=0.066

Group B

Slow (R2) (°)

Pre:15 (10/20)

Post: 20 (13.5/20)

p=0.0.465

Rapid (R1) (°)

Pre: 10 (5/11)

Post: 15 (11/20)

p=0.092

Difference

Pre: 5 (0/10)

Post: 0 (0/0)

p=0.206

Group C

Slow (R2) (°)

Pre: 20 (17.5/20)

Post: 20 (10/20)

p=0.102

Rapid (R1) (°)

Pre: 20 (15/20)

Post: 20 (10/20)

p=1.000

Difference

					Pre:0 (0/2.5) Post: 0 (0/0) p=0.180 p value between group=0.140
Kalkman et al. (2019) United Kingdom	RCT/Low	Participants (n=22), randomly divided into two groups Inclusion criteria: Age between 7 to 14 years old Diagnosed with spastic CP GMFCS level I-III Ability to perform at least one bilateral heel raise Exclusion criteria Received BTX injection 6 months prior to testing Have baclofen pump Any lower-limb neuro-or orthopaedic surgery Duration of study: 10 weeks	IG (n=12) Stretching exercise 1.ankle active stretching -1 minutes, 30 repetitions with 30 seconds rest in between Strength training: 1.unilateral heel raises -3 sets 12 repetitions Only strength training was performed in the first 4 weeks followed by combined intervention in another 6 weeks. Exercises were performed 4 times a week which 1 session was supervised and other 3 were performed at home. CG (n=10) Strength training for upper extremities Stretching exercise: ankle active stretching (1 minutes, 30 repetitions with 30 seconds rest in between)	Tendon stiffness during maximal voluntary isometric plantarflexion contraction (MVC) Resting fascicle length	Post-intervention Participants (n=16) IG (n=9) CG (n=7) <u>Tendon stiffness</u> Group A: 13.6N/m Group B: 1.5N/m p-value= 0.04 <u>Resting fascicle length</u> Group A: 2.2mm Group B: -0.5mm *p-value=0.02
Fosdahl et al. (2019) Norway	RCT/Low	Participants (n=37), randomly divided into two groups Inclusion criteria: Age between 7 to 15 years old	IG (n=17) Stretching exercise: 1.active knee extension	Passive and active popliteal angle (PPA and APA) Hamstring catches using Modified Tardieu Scale	Post-intervention (Intervention group compared to control group)

<p>Stretching and Progressive Resistance Exercise in Children with Cerebral Palsy: A Randomized Controlled Trial</p>	<p>Diagnosed with spastic bilateral CP GMFCS level I-III PPA 35° or more on the most affected leg</p> <p>Exclusion criteria BTX injections in the LL for the last 6 months Surgical procedure on hamstring or bilateral lengthening of the triceps surae Other surgical procedure in the lower limbs less than 1 year prior to inclusion Less than 0° DF in the ankle joint Less than 5° external rotations in the hips Not able to cooperate or understand instructions</p> <p>Duration of study: 32 weeks, 16 weeks of interventions (T1) followed by 16 weeks of maintenance (T2)</p>	<p>(5 seconds) followed by passive stretching (40 seconds) 2.seated hamstring stretch (45 seconds) -performed bilaterally 5 times</p> <p>Strength training: 1. multijointed PRE with loaded backpack -step up -squat -heel rise (progressive resistance) (repetitions progressed from 2 series of 12 repetitions to 3 series of 8 repetitions after 8 weeks) 2. terminal knee extension with manual resistance at distal leg</p> <p>Exercises were performed 3 times a week which 2 session was supervised and other 1 were performed at home.</p>	<p>(MTS) R1 with 90° flexion of knee</p> <p>Isokinetic quadriceps and hamstring strength (Cybex 6000)</p>	<p>After dropouts Participants (n=34) IG (n=16) CG (n=18)</p> <p>The result was presented in mean difference (SD)</p> <p><u>PPA and APA</u> <u>IG</u> <u>PPA</u> <u>Left</u> T0-T1:5.0 (4.8) T0-T2:3.5 (4.3) p=0.315 <u>Right</u> T0-T1: 5.4 (4.8) T0-T2:1.5 (85.7) p=0.234 <u>APA</u> <u>Left</u> T0-T1: 6.7 (7.3) T0-T2: 3.8 (8.6) P=0.120 <u>Right</u> T0-T1:9.2 (8.5) T0-T2: 5.0 (8.5) p=0.144</p> <p><u>CG</u> <u>PPA</u> <u>Left</u> T0-T1:1.0 (5.3) T0-T2:0.3 (5.5) p= 0.432 <u>Right</u> T0-T1: 1.2 (6.0) T0-T2:1.3 (5.4) p=0. 820 <u>APA</u> <u>Left</u> T0-T1: -1.6 (10.3) T0-T2: -1.7 (10.1) P=0.424 <u>Right</u> T0-T1:1.8 (8.8)</p>
		<p>CG (n=20) Not introduced to new interventions</p>		

T0-T2: 1.0 (10.2)
p=0.705

Hamstring catch

IG

Left

T0-T1: 0.7 (10.1)

T0-T2: 1.9 (7.9)

p=0.747

Right

T0-T1: -1.2 (13.5)

T0-T2: -0.7 (9.2)

p= 0.749

CG

Left

T0-T1: 0.7 (7.3)

T0-T2: -1.8 (9.2)

p=0.744

Right

T0-T1: 0.8 (12.0)

T0-T2: -4.7 (9.2)

p=0.744

Cho & Lee (2020) Korea	RCT/Low	Participants (n=25), randomly divided into two groups	IG (n=13) Stretching exercise: ROM stretching for 3 minutes prior to the session and 2 minutes at the end of the session Strength training: 1. sit to stand (5 minutes) 2. half-kneeling standing up (10 minutes) 3. side step-up (10 minutes) Exercises were performed 30 minutes per day, 3 times a week CG (n=12) Received: conventional therapy	Knee extensor strength Rehabilitative Ultrasound Imaging (RUSI) Muscle tone: Popliteal angle (PA) in active (-A), passive (-P) and speed (-S) (Electronic goniometer) Dynamic balance GMFM	Post-intervention No dropouts reported <u>IG (p-value)</u> PPA (non- dominant) = 0.030 PPA (dominant) =0.018 SPA (non-dominant) =0.014 SPA (dominant)=0.065 APA (non-dominant) =0.001 APA (dominant)=0.000 <u>CG</u> PPA (non- dominant) =0.101 PPA (dominant) =0.978 SPA (non-dominant) =0.163 SPA (dominant)=0.303 APA (non-dominant) =0.104 APA (dominant)=0.485 Between group PPA (non- dominant) = 0.046
Effect of Functional Progressive Resistance Exercise on Lower Extremity Structure, Muscle Tone, Dynamic Balance and Functional Ability in Children with Spastic Cerebral Palsy		Inclusion criteria: Age between 6 to 13 years old Diagnosed with spastic diplegic CP GMFCS level I-III Able to follow instructor's instruction Exclusion criteria Received any treatment for spasticity (surgery or BTX injection) in the last 6 months Has any disease that interfered with physical activity Duration of study: 6 weeks			

				1.functional electrical stimulation (FES) 2.mat activity 3.standing frame	PPA (dominant) = 0.020 SPA (non-dominant) =0.025 SPA (dominant)=0.222 APA (non-dominant) =0.346 APA (dominant)=0.213
Ryan et al. (2020) United Kingdom	RCT/ Moderate	Participants (n=64), randomly divided into two groups	IG (n=33) Stretching exercise: Plantarflexor stretches before and after exercise Strength training: 1. seated straight knee calf press against resistance band 2. standing straight knee calf raise 3.standing straight knee calf raise with hack squat 4.seated straight knee calf press with leg press machine (All strength training were done 6-15 repetitions 50%-85% of 1 RM for 22 weeks) Exercises were performed 30 minutes per day, 3 times a week	Gait efficiency Physical activity (accelerometer-Actigraph wGT3X) Participation-Assessment of Life Habits (Life-H) Muscle-tendon mechanics Muscle strength Muscle anatomical cross-sectional area Tendon-cross sectional area Muscle and tendon length Muscle and tendon stiffness (Young's modulus) Muscle, tendon and fascicle strain Treadmill walking	Post-intervention After dropouts Participants (n=52) Group A compared to Group B <u>Knee flexion angle during mid stance</u> Mean difference: -10.94° p<0.001 <u>Achilles tendon stiffness</u> Mean difference: +206.00MPa p=0.034
Wu et al. (2011) USA	Quasi-experimental /Moderate	Participants (n=12) Inclusion criteria: Age between 5 to 15 years old Diagnosed with spastic CP GMFCS level I-III	Receive: Stretching exercises: passive stretching of DF and PF 1.20 minutes for warm up	Passive ROM (PROM) of DF Active ROM (AROM) of DF Joint stiffness MTS MAS DF and PF muscle strength	Post-intervention No dropouts reported <u>MTS</u> p=0.02 at DF but no changes were seen at other joints

Lower-Limb Impairments in Children with Cerebral Palsy Using a Portable Robot	Able to walk with an assistive device independently Had enough cognitive ability to actively participate in the training protocol Exclusion criteria No surgical within the preceding year and serial casting withing 6 months Duration of study: 6 weeks	2.10 minutes for cooling down Strengthening exercises: 1.active assisted PF and DF to the available PROM (15 minutes) 2.resisted PF and DF within available AROM (15 minutes) Exercises were performed 3 sessions per week for 6 weeks	Selective Control Assessment of the Lower Extremity (SCALE) Functional outcome (PBS, 6MWT and TUG)	<u>MAS</u> p=0.01 at both PF and DF <u>PROM</u> <u>DF</u> Pre: 20.7±4.6° Post:26.6±4.9° (P=0.002) <u>AROM</u> <u>DF</u> Pre: 3±6.4° Post:10.1±8.7° (P=0.02) <u>Joint stiffness</u> Pre: 0.19±0.04 N m/° Post: 0.17±0.04 N m/° (P=0.03)	
Zhao et al. (2011) USA Changes of calf muscle-tendon biomechanical properties induced by passive-stretching and active-movement training in children with cerebral palsy	Quasi-experimental/ Moderate	Participants (n=7) Inclusion criteria: Age between 5 to 15 years old Diagnosed with spastic CP GMFCS level I-II Able to walk with an assistive device independently Had enough cognitive ability to actively participate in the training protocol Duration of study: 6 weeks	Receive: Stretching exercises: passive stretching (20 minutes for warm up, 10 minutes for cooling down) Strengthening exercises: resisted plantarflexion and dorsiflexion active movement by the robotic device within their ROM Exercises were performed 3 sessions per week for 6 weeks	Fascicle length and pennation angle Fascicular stiffness Tendon properties *all measuring the soleus and gastrocnemius muscles	Post-intervention No dropouts reported <u>Fascicle length</u> <i>Soleus at full knee extension and 0° ankle dorsiflexion</i> Pre: 24.8±8.2 mm Post:26.8±8.6 mm P=0.018 <i>Soleus at 90° knee flexion and 0° ankle dorsiflexion</i> Pre: 40.2±6.6 mm Post:41.5±5.9 mm P=0.018 <i>GM at full knee extension and 0° ankle dorsiflexion</i> Pre: 24.8±8.2 mm Post:26.8±8.6 mm P=0.018 <i>GM at 90° knee flexion and 0° ankle dorsiflexion</i> Pre: 29.3±6.2 mm Post:30.9±5.5 mm P=0.018

Pennation angle

Soleus at full knee extension and 0° ankle dorsiflexion

Pre: 24.5±4.8°

Post: 22.1±4.5°

P=0.028

Soleus at 90° knee flexion and 0° ankle dorsiflexion

Pre: 24.9±4.9°

Post: 22.3±4.6°

P=0.028

GM at full knee extension and 0° ankle dorsiflexion

Pre: 16.7±2.9°

Post: 16.0±2.8°

P=0.028

GM at 90° knee flexion and 0° ankle dorsiflexion

Pre: 21.9±4.0°

Post: 20.8±3.3°

P=0.043

Fascicular stiffness

Soleus at full knee extension and 0° ankle dorsiflexion

Pre: 33.3±10.4 N/mm

Post: 27.6±12.5 N/mm

P=0.128

GM at full knee extension and 0° ankle dorsiflexion

Pre: 12.2±3.8 N/mm

Post: 9.6±3.6 N/mm

P=0.018

Achilles Tendon Mechanical Properties

Achilles tendon length

Pre: 55.7 ± 9.9 mm

Post: 52.6 ± 9.4 mm

P=0.018

Achilles tendon stiffness
 Pre: 86.8 ± 16.9 N/mm
 Post: 114.4 ± 16.0 N/mm
 P=0.018

Young's modulus
 Pre: 113.6 ± 34.9 MPa
 Post: 136.8 ± 38.8 MPa
 P=0.018

<p>Lee et al. (2008) Korea</p> <p>Therapeutic effects of strengthening exercise on gait function of cerebral palsy</p>	<p>RCT/Low</p>	<p>Participants (n=16), randomly divided into two groups</p> <p>Inclusion criteria: Age between 4 to 12 years old Diagnosed with spastic diplegic or hemiplegic CP GMFCS level II-III Able to walk with or without walking aids</p> <p>Exclusion criteria Had BTX or phenol injections in the LL Surgical procedure on the LL Medical or orthopaedic diseases that prevent from exercising Had fixed contracture at the knee or hip joint of more than 25° Not able to cooperate or understand instructions</p> <p>Duration of study: 5 weeks</p>	<p>IG (n=9)</p> <p>Stretching exercise: 1. whole body stretching</p> <p>Strength training: 1. squat to stand 2. lateral step up 3. stair walk up and down 4. isotonic exercise of LL 5. isokinetic exercise using bicycle</p> <p>Exercises were performed 3 times a week, 60 minutes for a session.</p> <p>CG (n=8) Received: 1. conventional therapy (NDT, ROM exercise and gait training)</p>	<p>GMFM Muscle tone (MAS) Muscle strength (MMT) Functional test (lateral step up and squat to stand)</p>	<p>Post-intervention No dropout reported</p> <p><u>MAS</u> No significant changes in all patients of the experimental and control groups</p>
<p>Engsberg et al. (2006) USA</p> <p>Increasing Ankle Strength to Improve Gait and Function in Children with Cerebral Palsy: A Pilot Study</p>	<p>RCT/Low</p>	<p>Participants (n=15) divided into two groups, IG and CG. IG was further divided into three groups, PF, DF and PF&DF</p> <p>Inclusion criteria: Age below 18 years old Diagnosed with spastic diplegic CP</p>	<p>IG (n=12)</p> <p>Stretching exercise: 1. Gentle passive movement of the ankle throughout the ROM using the isokinetic device (10 minutes, prior and after strength training)</p>	<p>Ankle strength Ankle PF spasticity Gait GMFM Peds QL End range DF</p>	<p>Post-intervention After dropouts (n=12) IG (n=9) CG (n=3)</p> <p>Post-intervention <u>Spasticity (J/[°/S])</u></p>

GMFCS level I-III	Strengthening exercises:	<u>IG (Combined DF,PF, DF&PF)</u>
Ability to ambulate with or without walking aids	1. Eccentric and concentric contraction of DF, PF and DF&PF according to the designated group at different speed (30°/s and 90°/s).	Pre:0.012±0.007
Have passive DF at least -5° with knee extended and no greater than 15°		Post:0.006±0.005
Hamstring length (90/90 test) to 45° or less		*p<0.001
Ability to perform active DF and PF for approximately 20° of total active range	Each speed requires 3-5 repetitions for 6 sets, with 2 minutes rest between sets	<u>Individual training</u>
Able to perform six to eight repetitions of walking approximately nine metres	Exercises were performed 3 times per week for 12 weeks	<u>PF</u>
Able to follow verbal instructions		Pre:0.012±0.009
		Post:0.007±0.004
		<u>DF</u>
		Pre:0.013±0.006
		Post:0.004±0.003
		<u>PF&DF</u>
		Pre:0.015
		Post:0.008
		<u>CG</u>
		Pre:0.011±0.004
		Post:0.008±0.007
Exclusion criteria	CG (n=3)	
BTX injection in the LL in the past 6 months	Do not receive any treatment related to stretching or strengthening	
Orthopaedics intervention in the LL in the past 6 months		<u>DF RoM (°)</u>
Selective Dorsal Rhizotomy and intrathecal baclofen in the past 6 months		<u>IG (Combined DF, PF, DF&PF)</u>
Orthopaedics or medical problems that interfered with physical activity		Pre:7±6
Motor deficits secondary to neurological injury/illness beginning after first month of life		Post:12±5
Children with moderate to severe dystonia, athetosis, ataxia		p-value=0.073
		<u>Individual training</u>
		<u>PF</u>
		Pre:8±4
		Post:14±2
		<u>DF</u>
		Pre:2±5
		Post:10±6
		<u>DF&PF</u>
		Pre:11
		Post:10
		<u>CG:</u>
		Pre:8±5
		Post:10±4

*Only the results related to spasticity are presented. PBS= Paediatric Balance Scale; 6MWT= 6-minute walk test; TUG= Timed Up-and-Go test; Peds QL=Paediatrics Quality of Life questionnaire; FRT=Functional Reach Test; R1=The first point of resistance felt by therapist due to the catch result from the overactive stretch reflex; R2=passive joint ROM