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CONSTRAINT-INDUCED MOVEMENT THERAPY FOR LOWER EXTREMITY BALANCE AND FUNCTION IN POST-STROKE PATIENTS: A LITERATURE REVIEW

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ABSTRAK

Latar Belakang: *Constraint-induced movement therapy* (CIMT) terbukti sebagai intervensi neurorehabilitasi yang efektif untuk mengatasi "*learned non-use*" dan mendorong kemandirian fungsional pada pasien pasca-stroke. Namun demikian, penerapannya pada ekstremitas bawah (LE-CIMT) masih kurang dieksplorasi secara mendalam. Beberapa studi menunjukkan adanya ketidakkonsistenan hasil, terutama dalam hal pengaruh LE-CIMT terhadap variabel keseimbangan dan fungsi ekstremitas bawah pada pasien pasca-stroke. **Isi :** Untuk mengkaji pengaruh pemberian LE-CIMT terhadap keseimbangan dan fungsi ekstremitas bawah pada pasien pasca-stroke. Studi *literature review* pada artikel jenis *randomized controlled trial* (RCT) dalam rentang 10 tahun terakhir dengan pencarian artikel relevan pada *database* seperti PubMed, Physiotherapy Evidence Database (PEDro), Cochrane Library, serta Google Scholar pada bulan Desember 2024 hingga Februari 2025. Selanjutnya, artikel relevan dilakukan *appraisal* dengan skala *Physiotherapy Evidence Database* (PEDro) untuk mengevaluasi tingkat *bias* penelitian RCT. Tujuh artikel relevan memenuhi kriteria inklusi dan eksklusi penelitian dengan *moderate bias*. Hasil ekstraksi data menunjukkan adanya peningkatan signifikan (p<0.05) keseimbangan dan fungsi ekstremitas bawah setelah intervensi LE-CIMT dengan parameter seperti *Gait Analysis*, *Berg Balance Scale* (BBS), *Timed-Up Go Test* (TUG), dan *Fugl-Meyer Assessment of Lower Extremity* (FMA-LE). Perbaikan ini didasari mekanisme *cortical reorganization*. **Kesimpulan:** Intervensi LE-CIMT pada pasien pasca-stroke menunjukkan efek positif terhadap keseimbangan dan fungsi ekstremitas bawah.

Kata kunci: CIMT; Ekstremitas Bawah; Keseimbangan; Stroke

ABSTRACT

Background: Constraint-induced movement therapy (CIMT) has demonstrated effective as a neurorehabilitation intervention for addressing "learned non-use" and enhancing functional independence in stroke patients. However, its application to lower extremities (LE-CIMT) remains relatively unexplored. Several studies have shown inconsistent results, particularly regarding the effects of LE-CIMT on balance and lower extremity function in post-stroke patients. **Content :** To evaluate the impact of LE-CIMT on balance and lower extremity function in post-stroke patients. A literature review of Randomized Controlled Trial (RCT) articles published within the last 10 years was conducted. Relevant articles were searched across multiple databases including PubMed, Physiotherapy Evidence Database (PEDro), Cochrane Library, and Google Scholar from December 2024 to February 2025. Selected articles were appraised using the PEDro scale to assess the level of bias in randomized controlled trials. Seven articles meeting the inclusion and exclusion criteria were identified, all with moderate levels of bias. Data extraction revealed significant improvements (p<0.05) in balance and lower extremity function following LE-CIMT intervention across several outcome measures including Gait Analysis, Berg Balance Scale (BBS), Timed-Up Go Test (TUG), and Fugl-Meyer Assessment of Lower Extremity (FMA-LE). These improvements are attributed to mechanisms of cortical reorganization. **Conclusion:** LE-CIMT demonstrates positive effects on balance and lower extremity function in post-stroke patients.

Keywords: Balance, CIMT, Lower Extremity, Stroke.

INTRODUCTION

Stroke remains a leading cause of disability and the third most common cause of death worldwide, often resulting in significant impairments in sensory, motor, balance, and mobility functions (N.-H. Kim & Cha, 2015; Mir et al., 2014). Neuro-rehabilitation plays a crucial role in mitigating these clinical manifestations, with various therapeutic approaches aimed at improving functional independence and quality of life (Zhu et al., 2016).

Constraint-induced movement therapy (CIMT) has emerged as an effective neurorehabilitation intervention for addressing "learned non-use" by combining constraint of the unaffected extremities, intensive practice, behavioural shaping technique (Brainin & Heiss, 2019; Candan & Livanelioglu, 2017).

Numerous studies have demonstrated the positive effects of CIMT in enhancing upper extremity function and promoting greater independence in individuals with chronic stroke. These benefits have been observed both when CIMT is applied as a standalone intervention and combined with adjunct therapies, such as Kinesio taping, indicating its versatility and potential for synergistic outcomes (Hsieh et al., 2021; H. Kim et al., 2017; Rocha et al., 2021).

Over the past two decades, CIMT interventions have expanded to include applications for the lower extremities (LE-CIMT) in stroke patients (Aloraini, 2022). Regnaux et al. (2008) pioneered the use of constraint methods on unaffected limbs, reporting significant improvements ($p<0.05$) in gait speed, cadence, and paretic limb kinematics. However, Bonnyaud et al. (2013) did not observe similar effects in stroke patients following the LE-CIMT.

Despite these promising developments, the potential of LE-CIMT in enhancing motor recovery, particularly in terms of balance and functional performance of the lower limbs, remains relatively underexplored in the post-stroke population, with only limited of heterogenous trials (Menezes-Oliveira et al., 2024). This situation has created a clear evidence gap regarding the effectiveness and clinical applicability of LE-CIMT. Therefore, this literature review aims to critically examine and synthesize existing evidence regarding the effects of LE-CIMT on balance and lower extremity function in individuals recovering from stroke.

METHOD

This study employs a narrative literature review design, focusing on Randomized Controlled Trial (RCT) articles published within the last ten years. The narrative literature review approach is used to synthesize existing knowledge, identify research gaps, and provide a theoretical and clinical context for future investigations on LE-CIMT for balance and function.

The literature screening process began with a comprehensive search across multiple databases, including PubMed, Physiotherapy Evidence Database (PEDro), Cochrane Library, and Google Scholar, from December 2024 to February 2025. The search utilized keywords such as "Constraint-induced Movement Therapy", "CIMT", "mCIMT", "Lower Extremity", "Balance", "Lower Extremity Function", and "Stroke". Table 1 presents the complete list of search keywords.

Following the database search, articles were selected based on predefined inclusion and exclusion criteria. Inclusion criteria encompassed human studies involving stroke patients, English-language, articles published within the last decade, RCT design, presence of intervention and control groups, and primary data. Exclusion criteria comprised non-full-text articles, duplicate publications, and non-RCT study designs. The article selection process is summarized in Figure 1 using a PRISMA-style flow diagram for illustrative purposes.

All articles that met the inclusion and exclusion criteria were subjected to a methodological quality assessment using the Physiotherapy Evidence Database (PEDro) scale. This tool is widely used to evaluate the internal validity and statistical reporting of randomized controlled trials (RCTs), providing a standardized measure of risk of bias. The detailed appraisal results for the selected articles are summarized in Table 2.

RESULTS

The literature search yielded 981 articles across all databases using relevant keywords. However, only seven articles met the inclusion and exclusion criteria of this review, and the PEDro scale appraisal revealed that all selected articles had moderate bias. Studies with a moderate risk of bias are susceptible to certain methodological limitations; however, these do not necessarily invalidate their findings. These studies often lack sufficient information, which makes it challenging to assess potential problems with full confidence. Nonetheless, they can still be included in the analysis, provided their limitations are acknowledged and carefully considered when interpreting the results (Cochrane Methods, 2021).

Based on the extracted data, the studies were conducted in diverse geographic locations, including Brazil, South Korea, Saudi Arabia, Nigeria, Turkey, and China. This wide geographical distribution provides a global and comprehensive perspective on stroke rehabilitation, allowing for broader insights into the implementation and outcomes of various rehabilitation strategies across different settings.

Study characteristics varied among the included articles. Most studies focused on patients in the chronic stage of stroke recovery, typically more than six months post-stroke. However, Abdullahi et al. (2021) included patients at all stages of stroke, while Candan et al. (2017) studied stroke patients between 3-12 months post-onset, with an age range of 60-65 years.

Several confounding variables were identified across the included studies. Gender distribution was relatively balanced in most, although a few demonstrated a slight predominance of female participants, which may influence generalizability. Additional confounding factors included body mass index, pre-morbid footedness, which may impact movement patterns, mobility; and various baseline post-stroke characteristics such as balance level, lower extremity range of motion, and walking speed in each patient.

Dropout rates varied considerably among the studies. Three studies reported no dropouts, while the highest dropout rate was observed in Menezes-Oliveira et al. (2024), where 9 out of 42 recruited patients were lost to follow-up. Other studies reported lower dropout rates, ranging from 1 to 3 participants. These findings highlight the heterogeneity in stroke rehabilitation research. Table 3 presents comprehensive information on each study using the PICO.

LE-CIMT produced consistent, clinically meaningful improvements in both static and dynamic balance across four independent studies (Aloraini, 2022; Candan & Livanelioglu, 2017; e Silva et al., 2017; Park et al., 2024). Static balance (BBS) improvements were substantial (within-group F-values > 100, $p < 0.001$), with between-group effect sizes ranging from small-to-moderate ($\eta p^2 = 0.19–0.78$). Dynamic balance enhancements were similarly significant, with large within-group effect sizes ($d > 0.80$) and statistically superior between-group differences favoring CIMT across all three dynamic parameters.

Futhermore, LE-CIMT showed consistent improvements in lower extremity functional capacity across multiple dimensions of motor performance (Abdullahi, Aliyu, et al., 2021; Aloraini, 2022; Menezes-Oliveira et al., 2024; Zhu et al., 2016). Functional mobility assessments demonstrated significant gains ($p<0.05$) in 6MWT performance, reflecting improved walking endurance. Gait parameters, including velocity and stride characteristics, improved significantly ($p<0.05$) across studies. Broader motor function assessments also documented improvements in strength, control, and movement quality.

Table 1. Search keywords used in database queries

Databases	Keywords	Articles Retrieved	Article Included
PubMed	("Constraint-Induced Movement Therapy"[All Fields] OR "CIMT"[All Fields] OR "mCIMT"[All Fields]) AND ("Lower Extremity"[MeSH Terms] OR "Lower Extremity Function"[All Fields]) AND "Balance"[All Fields] AND "Stroke"[MeSH Terms] AND "humans"[MeSH Terms] AND "english"[Language] AND ((y_10[Filter]) AND (clinicaltrial[Filter]) AND (humans[Filter]) AND (english[Filter]))	10	4
PEDro	Constraint-induced Movement Therapy, CIMT, Stroke	94	1
Cochrane Library	Constraint-induced Movement Therapy OR CIMT OR mCIMT AND Lower Extremity OR Balance AND Stroke	59	0
Google Scholar	Constraint-induced Movement Therapy OR CIMT AND Lower Extremity AND Balance AND Stroke	818	2

DISCUSSION

Constraint-induced movement therapy (CIMT) has gained widespread recognition as an effective approach for improving limb function in patients with neurological disorders, including stroke (Abdullahi et al., 2021; Aloraini, 2022).

This intervention comprises three main components: (1) repetitive and task-oriented exercises; (2) a transfer package and behavioral strategies; and (3) movement of the paretic extremity (Menezes-Oliveira et al., 2021). In lower extremities, the LE-CIMT program shows potential for improving balance, ambulation, and LE function in stroke patients (Aloraini, 2022).

Data extraction from relevant articles revealed significant improvements in balance outcomes. This aligns with a meta-analysis by Tedla et al. (2022), which found CIMT had a significant effect on balance, with a mean difference of 0.51 against the control group. The mechanism underlying balance improvement is thought to involve intensive, repetitive, task-oriented exercises in CIMT (Abdullahi et al., 2021; Marklund et al., 2023). The “massed practice” paradigm enhances neuromuscular control, weight-bearing symmetry, and proprioceptive integration in the affected limb (Abdullahi et al., 2021; Marklund et al., 2023). Furthermore, by constraining the less-affected limb, LE-CIMT prevents compensatory strategies and forces the affected limb to assume a primary role in postural control (Marklund et al., 2023). LE-CIMT protocols also often integrate functional activities targeting postural stability and dynamic balance, thereby optimizing activation of neural mechanisms underlying postural stability and functional balance recovery in individuals with stroke (e Silva et al., 2017; Marklund et al., 2023).

Regarding lower extremity function, LE-CIMT showed promising results. These improvements are based on cortical reorganization mechanisms (Taub et al., 2014). CIMT significantly enhances neuron recruitment in the contralesional motor cortex and triggers an increase in bilateral motor component activation, evidenced by increased c-fos expression as a marker of neuronal activity (Liu et al., 2019; A. Zhang et al., 2024). CIMT also increases dendritic plasticity and dendritic spines in the bilateral somatosensory cortex through increased expression of GluR2 and neurotrophic factors such as BDNF, triggering limb function recovery (Hu et al., 2020; Liu et al., 2019). Additionally, CIMT induces improvements in brain structure, such as motor map expansion and cortical activation patterns (Kwakkel et al., 2015; Liu et al., 2019). Increased functional mobility is also directly influenced by improved balance and proper weight bearing resulting from CIMT (e Silva et al., 2017). Enhanced balance provides the dynamic stability required for safe ambulation by enabling effective control of the center of mass within the base of support during functional tasks (e Silva et al., 2017; Tedla et al., 2022). Concurrently, more symmetrical weight distribution increases loading of the affected limb, stimulating muscle activation patterns necessary for generating propulsive force during push-off (J. Zhang et al., 2023).

However, several limitations should be considered in implementing LE-CIMT. First, most studies focused on chronic stroke patients, making it difficult to generalize results to all stroke phases, especially acute and subacute. Neuroplasticity responses in early stroke phases may differ from chronic phases (Zhou et al., 2022). Second, there was considerable variation in LE-CIMT protocols across studies, particularly regarding training duration, intensity, and task selection. Most studies employed modified CIMT (mCIMT) protocols with 2-3 hours of daily exercise, which may not evaluate the therapeutic effect of conventional CIMT (Marklund et al., 2023; Zhou et al., 2022). Third, outcome measurements were heterogeneous, encompassing different balance, gait, and functional mobility assessments, complicating direct comparisons across studies. Finally, the relatively small sample sizes commonly reported reduced statistical power for drawing more general conclusions.

Future research should evaluate standardized LE-CIMT protocols across all stroke phases using consistent outcome measures and larger, more diverse populations.

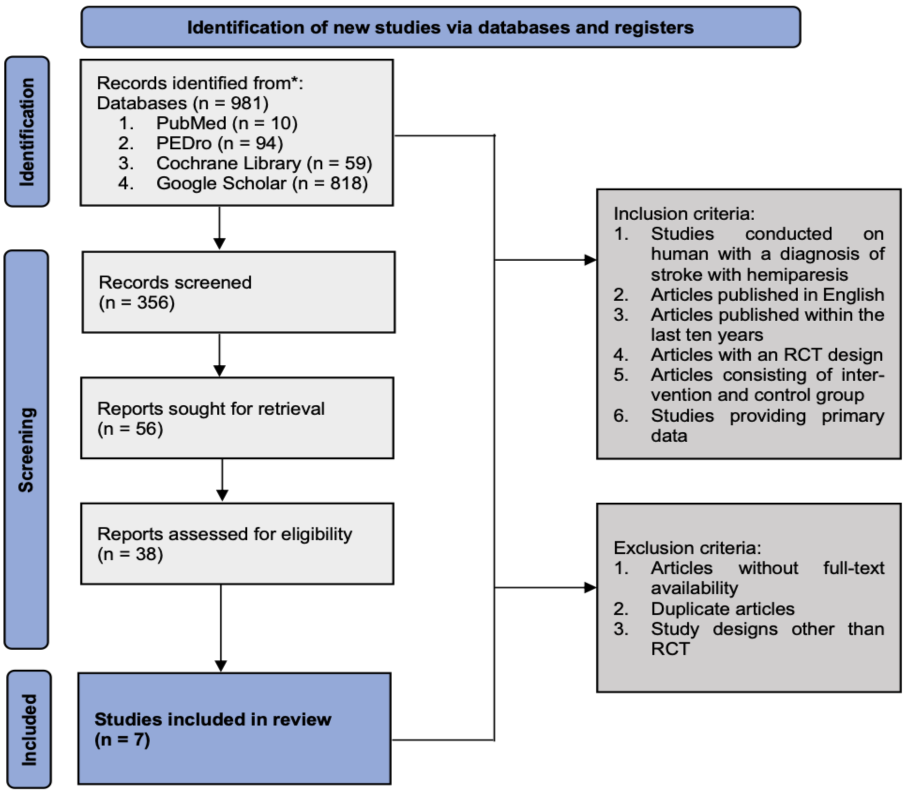

Figure 1. PRISMA flow diagram of study selection process

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Table 2. PEDro scale appraisal results for selected articles

PEDro Scale	Menezes et al. 2024	Park et al. 2024	Aloraini SM. 2022	Abdullahi et al. 2021	E Silva et al. 2017	Candan et al. 2017	Zhu et al. 2016
Eligibility criteria	1	1	1	1	1	1	1
Random allocation	1	1	1	1	1	1	1
Concealed allocation	0	0	0	1	1	0	0
Baseline comparability	1	1	1	1	1	1	1
Blind subjects	0	0	0	0	0	0	0
Blind therapists	0	0	0	0	0	0	0
Blind assessors	1	1	1	1	1	1	1
Adequate follow-up	1	1	1	1	1	0	0
Intention-to-treat analysis	1	0	1	1	1	0	0
Between-group comparisons	1	1	1	1	1	1	1
Point estimates and variability	1	1	1	0	1	1	1
Total Score	7/10	6/10	7/10	7/10	8/10	5/10	5/10
Level of Bias	Moderate						

Table 3. Summary of included studies using PICO framework

Authors	Patients	Interventions	Comparisons	Outcomes: Measurement	Outcomes: Research
Menezes-Oliveira et al. 2024	42 chronic stroke patients (≥6 months) with hemiparesis, walking ability deficit, capable of hip and knee flexion in the paretic lower extremity, independent transfer, able to walk at least 10 meters, and with a caregiver. Exclusion criteria included speech disorders and any events that would prevent the patient from continuing the intervention.	LE-CIMT for 3 hours/day for 15 consecutive days. - Intensive supervised training for 2.5 hours using individualized shaping technique with 8-12 tasks. - Transfer package for 30 minutes including monitoring, problem-solving, behavioral contact, homework.	Physiotherapy program for 2.5 hours/day for 15 consecutive days. Exercises included gait training, balance training, and lower limb strengthening.	- Gait analysis measured with 3-DGA and 6mWT. - Dynamic balance measured with TUG. - Lower extremity function measured with LE-MAL.	- The LE-CIMT group showed greater improvements in 6mWT (51.83; p=0.02) and spatiotemporal gait parameters, including step length (p=0.01), double support (p=0.04), and speed (p=0.03) compared to the control group. - For functional parameters, the LE-CIMT group showed significantly greater effects on the LE-MAL assistance subscale (1.09; p=0.04). - No significant difference (p>0.05) was observed in dynamic balance.
Park et al. 2024	40 stroke patients with inclusion criteria of hemiparesis >6 months, MMSE ≥24, and Brunnstrom stage >3. Exclusion criteria included neurological disorders other than stroke, orthopedic disorders of the lower limbs, visual or hearing impairments, and history of >1 stroke.	sEMG-triggered CIMT, comprising: - 10-minute warm-up at a comfortable speed. - Three 10-minute training periods with 1-minute rest intervals. - 5-minute cool-down.	General Cycling Training (GCT), including: - Regular stationary bicycle without sEMG-triggered device. - Total training time equivalent to CIMT group.	- Static balance assessed using the Postural Measurement System G300 from Metitur Ltd., Finland. - Dynamic balance evaluated with TUG, BBS, and FRT.	- No significant changes in static balance as measured by sway velocity (p>0.05) were observed in either group. - Both groups demonstrated significant improvements in all three dynamic balance parameters (p<0.05; d > 0.80). However, these changes were more pronounced (p<0.05) in the CIMT group.

Aloraini SM. 2022	38 patients from a healthcare center in Saudi Arabia. Inclusion criteria: age ≥18 years, no more than one stroke in the past year, lower extremity hemiparesis, BBS ≥35, MMSE ≥24. Exclusion criteria: excessive pain on the affected side (VAS >4/10), mAS ≥3, presence of neuropsychiatric disorders.	LE-CIMT comprising 3 hours of physical training and 30 minutes of transfer package daily for 2 weeks. - Progressive and task-oriented physical training, including step-up exercises. - Transfer package including behavioral contract.	Conventional stroke rehabilitation program including range of motion exercises, stretching, balance walking, and endurance training.	- FMA-LE to assess lower extremity function. - BBS to evaluate balance.	- Significant improvement in lower extremity function (p<0.001) following LE-CIMT. - No significant difference between groups (p>0.05), but the CIMT group showed higher mean FMA-LE scores compared to the control. - Significant improvement in balance (p<0.001) after LE-CIMT intervention. - The CIMT group demonstrated higher mean BBS scores.
Abdullahi et al. 2021	58 stroke patients aged ≥18 years, with MMSE ≥24, asymmetric posture, able to stand and walk with minimal assistance as assessed, and active knee flexion ≥15 degrees on the affected side while standing. Exclusion criteria included severe pain and hemineglect.	LE-CIMT protocol using 600 task repetitions/day. - Training dose: 5 days /week, 3 sessions/day with 40 repetitions per session (total 200 reps) or 600 reps/day for 4 weeks. - Exercises were task-oriented, such as side stepping, ball kicking, and stair climbing.	LE-CIMT protocol using 3 hours of training/day, 5 days a week for 4 weeks.	- Lower extremity function assessed with FMA-LE. - Balance measured using BBS.	- Both LE-CIMT methods significantly improved lower extremity motor function and balance (p>0.05). - When compared, the LE-CIMT protocol with 600 task repetitions/day was more effective in improving post-stroke outcomes based on knee extensor spasticity levels and exertion.
E Silva et al. 2017	38 stroke patients aged 21 to 70 years. Inclusion criteria: first-time stroke, gait disturbance, ability to walk independently for at least 10 m, slow to moderate walking speed. Exclusion criteria: cardiac conditions, balance disorders, blood pressure fluctuations, and pain.	- Prior to intervention, both groups performed a transfer package for 3 sets of 10 repetitions. - From day 1 to 9 of intervention, subjects underwent treadmill training with constraint on the unaffected ankle using a weight equal to 5% of	Treadmill training without ankle resistance for 30 minutes.	- BBS to assess static and dynamic postural balance. - TUG test to evaluate lower extremity functional mobility.	- Both groups showed significant improvement in postural balance (p<0.001), with the intervention group demonstrating a slightly greater increase in mean BBS scores. - Functional mobility improved significantly (p<0.01; F=18.33) in the intervention group.

		BW for 30 minutes.			
Candan et al. 2017	30 stroke patients aged >18 years with Brunnstrom stages III-V, capable of following the training program. Exclusion criteria included recurrent stroke, comorbidities such as cardiac pacemaker, cognitive impairment, and neurological or orthopedic disorders interfering with training participation.	mCIMT with constraint on the lower extremity for 120 minutes/day, 5 days/week for 2 weeks. - Constraint involved knee immobilization and use of shoe insoles on the unaffected extremity. - Task-oriented exercises included weight bearing and stair climbing. - Transfer package included home activities using the paretic extremity.	Neurodevelop-mental Treatment (NDT) program for 120 minutes/day, 5 days/week for 2 weeks. Exercises included weight bearing, balance, and walking	- BBS for static and dynamic postural balance. - FAS, walking velocity, cadence, and step length ratio for gait assessment.	- Both groups showed significant improvements ($p<0.001$) in BBS scores, with the mCIMT demonstrating more significant ($p=0.002$) balance improvements compared to the control group. - Both groups experienced significant improvements in walking ability ($p<0.05$). However, mCIMT showed superior effects ($p<0.05$) compared to the NDT group across all measured parameters.
Zhu et al. 2016	22 stroke patients from Hua Shan Hospital and Fudan University. Inclusion criteria: persistent hemiparesis for 3-6 months, stable vital signs, Brunnstrom stages II-III, absence of comorbidities such as Alzheimer's disease, and no orthopedic disorders in the lower extremities. Exclusion criteria: MMSE score ≤23 and inability to perform physical exercises.	mCIMT focused on gait training for 2 hours per day, 5 days per week for 4 weeks. Exercises included sit-to-stand transfers, indoor walking training, stair climbing and descending, balance training, single-leg weight training, and muscle strength training.	Standard rehab-ilitation program for 45 minutes per day, 5 days per week for 4 weeks. Exercises consisted of passive and active exercises, as well as education and guidance.	Gait analysis using the Eagle Motion Analysis System (Motion Analysis Corp, Santa Rosa, CA).	- Significant improvements ($p<0.05$) in velocity, step length, and swing time of the non-paretic leg were observed after mCIMT intervention, while no such changes occurred in the control group. - Mean scores for step length and swing time of the paretic leg in the mCIMT group increased, but not significantly ($p>0.05$). Meanwhile, these scores relatively decreased in the control group.

CONCLUSION

Lower extremity constraint-induced movement therapy (LE-CIMT) appears to be an evidence-based and promising intervention for improving balance and lower extremity function after stroke. The available evidence suggests that LE-CIMT may be particularly beneficial for addressing post-stroke balance and motor function impairments during the subacute and chronic phases, when intensive, task-oriented training can be safely implemented. Nevertheless, further research is needed to optimize intervention protocols, standardize outcome measures across studies, and examine long-term effects on balance and lower extremity function. Addressing these gaps will improve consistency of the findings, strengthen clinical decision-making and advance the field of stroke rehabilitation.

CONFLICT OF INTEREST

The authors declare that there are no conflicts of interest.

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AUTHOR CONTRIBUTORS

M.E.S conceptualized the study, conducted data collection and analysis, and wrote the original draft of the manuscript, N.A and N.H conducted data collection and contributed to writing the original draft of the manuscript, and Z.B contributed to writing the original draft of the manuscript. All authors critically reviewed and revised the manuscript.

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