Original Article

Allied Medical Research Journal

Vol:4 No.3: 03-12

Comparative Effects of Mirror Therapy, Proprioceptive Neuromuscular Facilitation, and Constraint-Induced Movement Therapy on Upper Limb Motor Recovery in Stroke Survivors: A Three-Arm Randomized Controlled Trial

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ABSTRACT

Background: The majority of stroke survivors have upper-limb weakness, which reduces their functional independence in the real world, but there is limited evidence from trials that directly compare upper-limb rehabilitation interventions. The study compared the efficacy of three types of therapies (Mirror Therapy (MT), Proprioceptive Neuromuscular Facilitation (PNF), and Constraint-Induced Movement Therapy (CIMT)) in restoring motor function of the affected upper limb after stroke, when combined with conventional physiotherapy.

Methods: This was a three-arm parallel-group trial of 90 adults with post-stroke upper-limb hemiparesis, with blinded outcome assessment. The participants were allocated in a 1:1:1 ratio to MT, PNF, or CIMT, each with conventional physiotherapy, 6 days per week. The Action Research Arm Test (ARAT), Fugl-Meyer Assessment of the Upper Extremity (FMA-UE), Modified Ashworth Scale (MAS), and grip strength were measured by a blinded assessor at baseline and at 12 weeks.

Results: All 90 participants completed the trial with significant improvements from baseline on all four measures ($p<0.001$). A between-group difference at week 12 emerged only for the ARAT (one-way ANOVA, $F=9.335$, $p<0.001$): CIMT scored higher than both MT ($p=0.002$) and PNF ($p<0.001$), whereas MT and PNF were statistically indistinguishable. FMA-UE, MAS, and grip strength showed no between-group differences.

Conclusion: All three interventions improved upper-limb function with CIMT showing the greatest benefit in task performance, as measured by the ARAT. When CIMT is not feasible, MT and PNF are effective alternatives. This highlights the need to tailor therapy choices to each patient's goals and resources.

Keywords: *Motor Recover, Quality of Life; Rehabilitation; Stroke; Upper Extremity.*

Received: April 29th, 2026; **Revised:** June 25th, 2026; **Accepted:** July 9th, 2026

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DOI: https://doi.org/10.59564/amrj/04.03/001

INTRODUCTION

Worldwide, stroke ranks among the foremost causes of long-term disability, with over 12 million new cases each year and more than 100 million survivors living with lasting impairment[1]. Global burden-of-disease estimates likewise rank stroke among the leading contributors to disability-adjusted life years across all age groups[2]. The upper limb is affected more often than any other body region after stroke, with weakness present in roughly 55-85% of survivors during both the acute and chronic phases[3-4]. This typically appears as weakness, altered muscle tone, impaired coordination, and reduced dexterity, all of which limit a person's capacity to manage daily activities independently and erode quality of life[3]. Despite improved survival after acute stroke, only a small proportion of patients regain full use of the paretic arm, underscoring the ongoing need for effective, evidence-based approaches to upper limb rehabilitation[5].

A range of neurorehabilitation approaches, each grounded in a distinct neurophysiological rationale, is used to promote upper-limb recovery after stroke. Mirror therapy (MT) provides visual feedback that creates the illusion of normal movement in the affected limb, a mechanism thought to drive cortical reorganization and motor relearning[6]. Trials of MT, whether delivered conventionally or through virtual-reality enhancement, have repeatedly shown clinically meaningful gains in motor function, sensorimotor integration, and daily functioning when added to conventional therapy[6-9]. PNF instead relies on diagonal and spiral movement patterns, paired with proprioceptive stimulation, to enhance neuromuscular efficiency and reduce spasticity, and has been shown to improve motor control and functional independence in stroke survivors[10]. Among the most extensively studied approaches is constraint-induced movement therapy (CIMT), which restrains the unaffected limb to force intensive, repetitive practice with the paretic limb, thereby reversing learned non-use through use-dependent cortical plasticity[11-13]. Each of these three approaches outperforms conventional physiotherapy alone, though they act on distinct facets of neuroplasticity, motor learning, and behavioral adaptation.

Although evidence supports the efficacy of each approach individually, few trials have directly compared MT, PNF, and CIMT head-to-head within a single, adequately powered study. Most existing research has evaluated these therapies in isolation or against conventional therapy alone rather than against one another, leaving clinicians without a solid evidence base for choosing among them for a given patient[14,15]. This gap matters most in resource-limited settings, where selecting the most time- and cost-efficient option can shape both patient recovery and resource use. Adding to the uncertainty, many earlier comparative studies have relied on small sample sizes, a single outcome measure, or short follow-up periods, limiting the extent to which their conclusions about long-term upper limb recovery can be generalized.

Closing this gap calls for a well-designed, adequately powered randomized controlled trial that compares these three widely used interventions head-to-head using standardized, validated outcome measures. This study was therefore undertaken to determine how mirror therapy, proprioceptive neuromuscular facilitation, and constraint-induced movement therapy, each added to conventional physiotherapy, affect upper-limb motor recovery, functional performance, spasticity, and grip strength in people with post-stroke upper-limb hemiparesis.

METHODOLOGY

Study Design and Setting

This study was designed as a three-arm, parallel-group, assessor-blinded randomized controlled trial conducted in the Department of Physiotherapy, Ikram Hospital, Gujarat, Punjab, Pakistan, between July 2025 and January 2026. Eligible participants with post-stroke upper-limb hemiparesis were randomly allocated in equal numbers to one of three groups; Mirror Therapy (MT), Proprioceptive Neuromuscular Facilitation (PNF), or Constraint-Induced Movement Therapy (CIMT); each delivered alongside conventional physiotherapy.

Calculation of Sample Size

The number of samples was determined based on a previous trial comparing CIMT versus MT for hand function recovery after stroke, which found between-group Fugl-Meyer Assessment (FMA) scores of 27.461 ± 2.757 for the CIMT group and 24.923 ± 2.253 for the MT group[16]. The number of subjects needed was estimated using the standard formula for comparing two independent means:

$$n = 2\sigma^2(Z_{\alpha/2} + Z_\beta)^2 / (\mu 1 - \mu 2)^2$$

Where:

- $Z_{\alpha/2}$ = 1.96 (95% confidence level, two-tailed)
- Z_β = 0.84 (80% statistical power)
- σ = pooled standard deviation of the two groups
- ($\mu 1 - \mu 2$) = difference between group means

This indicated that each group should have about 16 participants, based on a pooled SD of 2.518 and a mean difference between groups of 2.538. This number was increased to 30 participants per group to account for drop-off and increase statistical power, for a total of 90 participants across the three arms.

Randomization and Allocation Concealment

A computer-generated random number sequence was used to assign eligible participants to one of the three intervention groups (MT, PNF, or CIMT). To conceal allocation, sequentially numbered, opaque, sealed envelopes (SNOSE) were prepared in advance and opened only after a participant had enrolled and completed baseline assessment; this step was carried out by an investigator with no role in delivering treatment or assessing outcomes.

Participants

Ninety participants with post-stroke upper-limb hemiparesis, aged 25–65 years, of either sex, were recruited from the Department of Physiotherapy, Ikram Hospital, Gujarat.

Inclusion Criteria:

- Clinically or radiologically confirmed stroke patients
- Both male and female participants
- Age range of 25–65 years
- Presence of unilateral upper limb hemiparesis

Exclusion Criteria:

- Inability to perform prescribed exercises
- Lack of willingness or denial to provide informed consent
- Cognitive impairment has already been diagnosed, affecting comprehension or protocol compliance

Interventions

All three groups received their assigned intervention in addition to conventional physiotherapy (passive/active range-of-motion exercises, positioning, and functional mobility training), delivered five sessions per week for six weeks, with outcome assessment repeated at the 12-week mark.

- **Mirror Therapy (MT) Group:** Participants were seated in front of a mirror box oriented in the mid-sagittal plane with the unaffected limb positioned in front of the mirror facing the participant and the affected limb behind the mirror. The participants performed a series of movements with the non-affected hand while observing the reflection of their own hand; this mechanism produced the illusion of normal motor function in the affected hand. Sessions lasted approximately 30 minutes and included 10-15 repetitions of each movement pattern, with rest breaks to reduce fatigue. It has been hypothesized that this visual input activates mirror-neuron networks and activates the premotor cortex in the affected side, thus promoting motor relearning and reorganization[6].

- **Proprioceptive Neuromuscular Facilitation (PNF) Group:** Participants were given manually resisted exercises based on Kabat's diagonal movement patterns (D1 and D2 Flexion/Extension patterns of the upper limb) as well as facilitation techniques such as rhythmic initiation, slow reversal, hold-relax, and contract-relax. The number of repetitions begun at each diagonal pattern was 10-15 per set, for a total of approximately 30 minutes of each session, and manual proprioceptive input (stretch, traction, and approximation) was applied to the shoulder, elbow, and wrist to maximize the recruitment of neuromuscular units, improve coordination, and decrease spasticity via reciprocal inhibition, respectively[10].

- **Constraint-Induced Movement Therapy (CIMT) Group:** Therapists prescribed wearing a padded mitt to restrict use of the non-affected upper limb for approximately 90% of waking hours during treatment and, if possible, during structured CIMT at home. Supervised sessions lasted approximately 30 minutes. They included intensive, repetitive, task-oriented practice with the affected limb using the "shaping" technique, which involves dividing functional tasks (e.g., reaching, grasping, transferring objects, and manipulating daily items) into successive approximations of increasing difficulty. The forced and repetitive use of the paretic limb is designed to reverse learned non-use and foster use-dependent reorganization of the cortex[11,12].

Outcome Measures

All outcome measures were recorded at baseline and after 12 weeks of intervention by a blinded assessor not involved in treatment delivery.

- **Action Research Arm Test (ARAT):** This is an observational test that consists of 19 items across four subtests (pinch, grasp, gross movement, and grip) with each subtest scored on an ordinal scale from 0 (no movement at all) to 3 (normal movement), for a maximum of 57 points, with higher scores indicating a better upper arm function. Both the Fugl-Meyer scale and the ARAT have good criterion validity in post-stroke patients with known motor impairments, and the ARAT exhibits excellent internal consistency across its items in this patient population[17].

- **Fugl-Meyer Assessment for Upper Extremity (FMA-UE):** This is a 33 Item performance-based assessment of motor impairment involving reflexes, movement within and outside of synergy, wrist and hand function, and movement speed and coordination. They are rated on a 3-point scale (0 = unable to perform, 1 = partial performance, 2 = full performance), with a maximum possible score of 66, where a higher score indicates less impairment. This is considered the gold-standard stroke rehabilitation research tool because of its reliability, validity, and responsiveness[18].

- **Modified Ashworth Scale (MAS):** This is a clinician-rated spasticity test designed to assess resistance to passive stretch of the shoulder adductors, elbow flexors, and wrist flexors. A 6-point scale (0, no increase in tone; 1, 1+, 2, 3, 4, affected part rigid in flexion or extension) is used; the modal grade is recorded from three passive movement trials (one per muscle group), and higher scores indicate greater spasticity. This is because its standardized scoring protocol has demonstrated good-to-excellent reliability, both within and between the scorers[19].

- **Grip Strength:** The maximal isometric grip strength of the affected hand was measured with the hand-held dynamometer setup when the participant sat with the shoulder adducted, elbow flexed at 90°, and forearm neutral. The final value was the mean of three trials with a short break between trials. This has been shown to have high test–retest and inter-rater reliability (ICC > 0.9) among stroke patients[20].

Statistical Analysis

SPSS (version 24.0) was used to analyze the data. Descriptive statistics (mean ± SD) were calculated for each outcome variable, and the Shapiro-Wilk test was performed to assess normality. The one-way analysis of variance (ANOVA) was used with Tukey's post hoc test for pairwise comparisons to compare the groups at baseline and at the end of the intervention. Changes within groups over time (baseline to week 12) were evaluated using paired t-tests or the Wilcoxon signed-rank test, depending on the data distribution. All outcome tabulations were presented as 95% confidence intervals (CIs), and statistical significance was defined as $p<0.05$.

Ethical Considerations

Approval for this study was obtained from the Institutional Review Board of Ikram Hospital, Gujrat (IRB No. IKG-002/24) prior to recruitment and registered prospectively with ClinicalTrials.gov (Registration No. NCT07683130).All procedures adhered to the ethical principles set out in the Declaration of Helsinki and its subsequent amendments. Each participant, or their legal attendant where relevant, provided written informed consent after receiving a complete explanation of the study procedures and their potential risks and benefits, and all participants were informed that they could withdraw at any time without affecting their ongoing clinical care.

RESULTS

Participant Flow and Baseline Characteristics

A total of 90 participants with post-stroke upper-limb hemiparesis were enrolled and evenly distributed across the Mirror Therapy (MT, n=30), Proprioceptive Neuromuscular Facilitation (PNF, n=30), and Constraint-Induced Movement Therapy (CIMT, n=30) groups, each receiving their assigned intervention alongside conventional physiotherapy. Every participant completed both the six-week intervention and the 12-week follow-up assessment, and none dropped out of any arm. The three groups were similar at baseline in demographic and clinical characteristics (Table 1); one-way ANOVA found no significant differences in age ($F = 0.20$, $p = 0.821$) or time since stroke ($F = 1.18$, $p = 0.311$), supporting adequate randomization, and gender, affected side, and stroke type were likewise distributed similarly across groups.

Table 1: Baseline demographic and clinical characteristics of the three treatment groups.

Characteristic	Mirror Therapy (n=30)	PNF (n=30)	CIMT (n=30)	p-value
Age, years (mean ± SD)	46.20 ± 8.12	46.83 ± 9.77	47.83 ± 8.52	0.821†
Time since stroke, months (mean ± SD)	7.22 ± 3.10	6.63 ± 3.12	6.11 ± 3.37	0.311†
Gender, Male / Female, n	16 / 14	18 / 12	18 / 12	
Affected side, Left / Right, n	15 / 15	17 / 13	15 / 15	
Stroke type, Ischemic / Hemorrhagic, n	19 / 11	28 / 2	23 / 7	

†One-way ANOVA

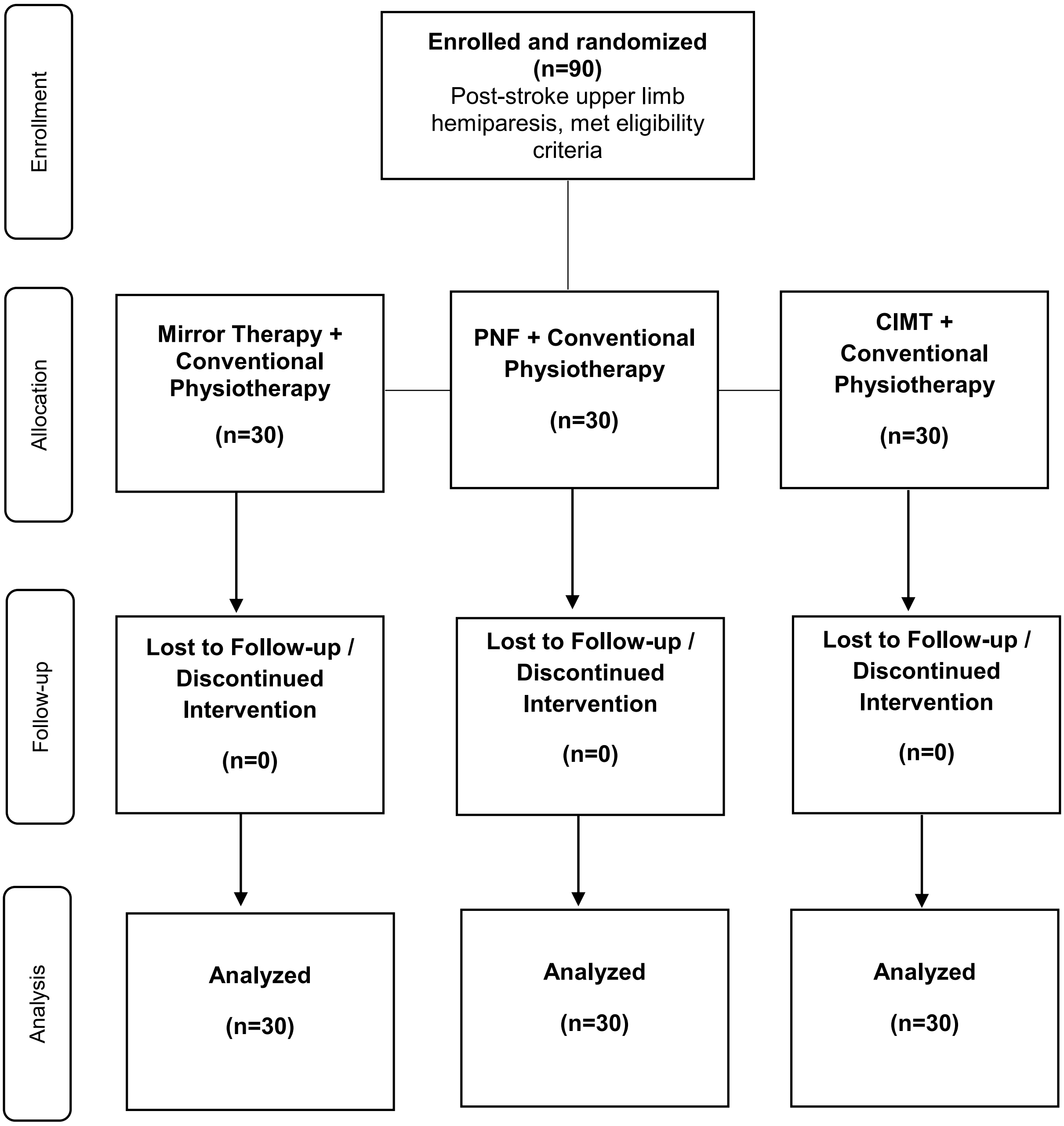

Figure 1. CONSORT diagram showing participant enrollment, group allocation, follow-up, and analysis

Baseline Comparability of Outcome Measures

None of the four outcome measures differed significantly between groups at baseline: ARAT (p=0.175), FMA-UE (p=0.487), MAS (p=0.483), and grip strength (p=0.689) (Table 2), one-way ANOVA, confirming that the three groups were closely matched on motor impairment and function before treatment began.

Table 2: Baseline and week-12 scores, within-group change, and between-group comparison for all outcome measures, by treatment group.

Outcome measure	Group	Baseline (mean ± SD)	Week 12 (mean ± SD)	Mean change ± SD	Within-group p-value	Between-group, baseline	Between-group, week 12
ARAT (0–57)	Mirror Therapy	20.73 ± 7.41	29.17 ± 6.81	8.43 ± 3.19	<0.001	F = 1.777, p = 0.175	F = 9.335, p < 0.001
	PNF	21.37 ± 7.63	28.47 ± 8.67	7.10 ± 3.33	<0.001		
	CIMT	23.93 ± 5.69	36.10 ± 7.08	12.17 ± 4.84	<0.001		

FMA-UE (0–66)	Mirror Therapy	30.97 ± 9.56	43.20 ± 9.05	12.23 ± 3.46	<0.001	F = 0.725, p = 0.487	F = 0.105, p = 0.900
	PNF	32.97 ± 10.60	42.60 ± 11.39	9.63 ± 5.04	<0.001		
	CIMT	30.03 ± 8.66	43.87 ± 11.45	13.83 ± 5.64	<0.001		
MAS (0–4)‡	Mirror Therapy	1.20 ± 0.90	0.98 ± 0.88	−0.22 ± 0.39	0.005	F = 0.735, p = 0.483	F = 0.788, p = 0.458
	PNF	1.28 ± 0.99	1.13 ± 0.96	−0.15 ± 0.33	0.017		
	CIMT	1.47 ± 0.71	1.27 ± 0.78	−0.20 ± 0.39	0.008		
Grip strength (kg)	Mirror Therapy	9.04 ± 3.40	11.89 ± 3.62	2.85 ± 1.12	<0.001	F = 0.374, p = 0.689	F = 1.337, p = 0.268
	PNF	8.33 ± 3.63	10.97 ± 3.85	2.65 ± 1.01	<0.001		
	CIMT	8.49 ± 2.91	12.42 ± 2.82	3.92 ± 1.17	<0.001		

‡MAS grades were coded numerically (0, 1, 1+ = 1.5, 2, 3, 4) for statistical analysis. Within-group p-values are from paired t-tests (ARAT, FMA-UE, grip strength) or the Wilcoxon signed-rank test (MAS); between-group p-values are from one-way ANOVA (df = 2,87).

‡MAS grades were coded numerically (0, 1, 1+ = 1.5, 2, 3, 4) for statistical analysis.

Action Research Arm Test (ARAT)

From baseline to week 12, all three groups showed significant within-group gains in ARAT score (paired t-test, p < 0.001 for each group; Table 2, Figure 2). The CIMT group gained the most (12.17 ± 4.84 points), ahead of Mirror Therapy (8.43 ± 3.19 points) and PNF (7.10 ± 3.33 points). One-way ANOVA identified a significant between-group difference in ARAT score at week 12 (F = 9.335, p < 0.001).

Post hoc Tukey testing confirmed that CIMT scored significantly higher on the ARAT than Mirror Therapy (mean difference = 6.93, 95% CI 2.28–11.59, p = 0.002) and PNF (mean difference = 7.63, 95% CI 2.98–12.29, p < 0.001), whereas Mirror Therapy and PNF did not differ significantly from one another (mean difference = 0.70, 95% CI −3.96–5.36, p = 0.932) (Table 3, Figure 2).

Table 3: Tukey's post hoc pairwise comparison for ARAT at week 12, the only outcome measure showing a significant overall between-group effect.

Group-wise comparison (ARAT, Week 12)	Mean difference	95% CI	p-adj (Tukey)
CIMT vs Mirror Therapy	6.93	2.28 to 11.59	0.002**
CIMT vs PNF	7.63	2.98 to 12.29	<0.001***
Mirror Therapy vs PNF	0.70	−3.96 to 5.36	0.932

***p < 0.01, ***p < 0.001.*

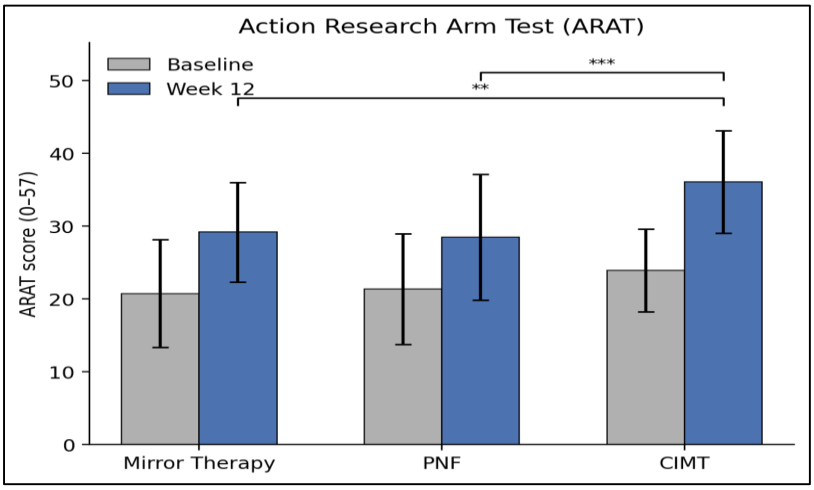

Figure 2: Mean ARAT scores (± SD) at baseline and week 12 across the Mirror Therapy, PNF, and CIMT groups. **p < 0.01, ***p < 0.001 (Tukey post hoc, Week-12 comparison vs CIMT).

Fugl-Meyer Assessment – Upper Extremity (FMA-UE)

All three groups improved significantly on the FMA-UE between baseline and week 12 (paired t-test, p < 0.001 for each group; Table 2, Figure 3), with average gains of 13.83 ± 5.64 points for CIMT, 12.23 ± 3.46 points for Mirror Therapy, and 9.63 ± 5.04 points for PNF. The between-group comparison at week 12 was not significant (F = 0.105, p = 0.900), meaning the three interventions led to similar reductions in motor impairment as captured by the FMA-UE.

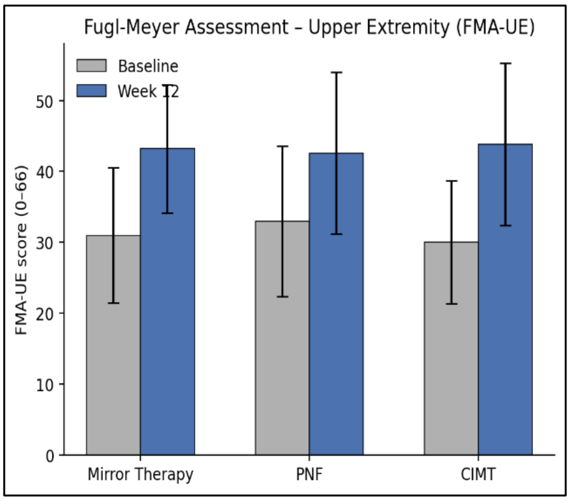

Figure 3: Mean FMA-UE scores (± SD) at baseline and week 12 across the three groups. One-way ANOVA showed no difference in the results between the groups at week 12 (p = 0.900).

Modified Ashworth Scale (MAS)

Spasticity, measured by the MAS, decreased significantly from baseline to week 12 in all three groups (Wilcoxon signed-rank test; $p = 0.008$ for CIMT, $p = 0.005$ for Mirror Therapy, $p = 0.017$ for PNF; Table 2), though the reduction was modest in every group. No between-group difference emerged at week 12 ($F = 0.788$, $p = 0.458$), pointing to a similar degree of spasticity reduction across all three treatment approaches.

Grip Strength

Maximal isometric grip strength of the affected hand rose significantly over the 12 weeks in every group (Table 2, paired t-test, $p < 0.001$ in each group). CIMT produced the largest within-group gain (3.92 ± 1.17 kg), ahead of Mirror Therapy (2.85 ± 1.12 kg) and PNF (2.65 ± 1.01 kg). Although this pattern favored CIMT, the difference between groups at week 12 was not statistically significant ($F = 1.337$, $p = 0.268$).

DISCUSSION

This three-arm trial aimed to compare Mirror Therapy, Proprioceptive Neuromuscular Facilitation, and Constraint-Induced Movement Therapy for upper-limb motor recovery in people with post-stroke hemiparesis. Every intervention led to significant within-group gains across all four outcomes, ARAT, FMA-UE, MAS, and grip strength demonstrating that each approach can drive meaningful recovery over a 12-week course. However, only the ARAT, which captures performance on functional tasks, revealed a statistically significant difference between groups: CIMT improved more than either Mirror Therapy or PNF, while the latter two produced similar gains. FMA-UE, MAS, and grip strength showed no between-group differences, suggesting the three interventions had broadly comparable effects on motor impairment, spasticity, and strength.

CIMT's greater gains on the ARAT align with the theoretical rationale of forced-use therapy, which counters learned non-use by restraining the unaffected limb and requiring intensive, repetitive, task-oriented use of the paretic limb[11-13]. Since the ARAT closely tracks real-world manipulative actions such as grasping, gripping, and pinching, it may be especially responsive to the task-specific, functionally grounded practice built into CIMT's shaping technique, where movements are drawn from everyday activities rather than isolated exercises. This mirrors a recent three-arm RCT that, for the first time, directly compared CIMT and MT and likewise found a greater, though not exclusive, advantage for CIMT in functional strength and independence measures[21].

It also aligns with a network meta-analysis of upper limb exercise interventions after stroke, which found task-specific and constraint-based training to be the most effective for restoring upper limb motor function[22], and with a separate network meta-analysis of non-conventional upper limb therapies, in which CIMT-based approaches consistently ranked among the top performers for activity-level outcomes[23].

Unlike the ARAT results, the lack of a significant between-group difference on the FMA-UE suggests that MT, PNF, and CIMT converge on a common pathway to recovery in motor impairment, rather than diverge. Because the FMA-UE assesses reflex activity, synergy patterns, and isolated joint movement rather than integrated functional performance[18], it may respond more to the overall amount of active practice matched here at five sessions weekly for six weeks—than to the particular training format (mirror feedback, proprioceptive facilitation, or forced use).

A comparative trial of modified CIMT, proprioceptive training, and task-oriented training reached a similar conclusion, reporting significant within-group gains across all three approaches with broadly equivalent outcomes, and suggesting that the amount and consistency of practice, rather than the specific technique used, drives recovery at the impairment level[24]. In line with this, a systematic review of dosing and timing in upper limb interventions after stroke found treatment intensity and duration to be the key drivers of motor recovery, regardless of which intervention was used[25].

Outcomes for Mirror Therapy and PNF were statistically indistinguishable across all four measures, echoing earlier comparative work indicating that these two therapies confer similar overall benefit despite working through different mechanisms[14,15]. MT is thought to aid recovery by engaging the mirror neuron system, recruiting ipsilateral motor pathways, and restoring interhemispheric connectivity between the two primary motor cortices, as a recent resting-state fMRI study has shown[26]. PNF, on the other hand, depends on manually resisted diagonal movement patterns and proprioceptive facilitation to boost neuromuscular recruitment and dampen spasticity via reciprocal inhibition[10]. The fact that these mechanistically distinct approaches yielded statistically equivalent clinical outcomes here implies that, at least in this population, several different neurorehabilitative routes can converge on similar functional gains when matched for intensity and duration.

Spasticity, as measured by the MAS, decreased significantly across all three groups, with no differences between them, indicating that adding MT, PNF, or CIMT to conventional physiotherapy produced a similarly modest anti-spastic effect. This aligns with a recent systematic review and meta-analysis reporting that MT reduces spasticity to a degree comparable to active exercise-based or traditional interventions, without clear evidence of superiority[27]. The modest average change in MAS grade seen across all three groups here may also reflect a ceiling effect, since baseline spasticity was already mild to moderate (1.20–1.47), leaving limited room for further reduction over the 12-week trial period.

Grip strength rose significantly across all groups, most markedly in the CIMT group, though the between-group difference fell short of significance. This is consistent with a modest, though not statistically significant, advantage for CIMT on hand-strength outcomes relative to MT, and aligns with evidence that hand-held dynamometry, while more reliable in stroke patients than in healthy controls, may lack the sensitivity to detect between-group differences of this magnitude without a larger sample or longer follow-up.

These findings align with earlier work reporting numerically greater hand-function gains with CIMT than with MT in cerebrovascular patients, without diminishing MT's value as a widely accessible, low-cost alternative[16]. Taken together with the present trial, the broader picture is that while CIMT can offer functional benefits, MT and PNF remain valuable options, particularly for patients unable to tolerate CIMT's demanding training schedule or restraint protocol. From a clinical and resource-allocation perspective, these findings carry implications for rehabilitation planning, particularly in resource-constrained settings such as the one in this study. Where the main rehabilitation goal is functional independence in activities of daily living (ADLs), CIMT may be the preferred choice; MT and PNF, being less equipment-, supervision-, and tolerability-intensive, may be better suited when CIMT is impractical due to severe impairment, poor adherence to restraint, or limited therapist availability[9,24].

Given that the three therapies produced equivalent effects on impairment, spasticity, and strength, therapy selection should hinge on patient preference, cognitive and physical tolerance, and available resources, rather than on the assumption that one approach is universally superior.

Strengths and Limitations

A three-arm randomized design, a sufficient sample size, standardized and validated outcome measures, blinded assessment, and full follow-up at 12 weeks without attrition further increase confidence in these results. However, there are some constraints to consider. First, the single-center design and the relatively homogeneous sociodemographic profile of participants may limit the generalizability of these results to other settings and populations. Second, because only outcome assessors were blinded, there is a possibility of performance bias if the therapist and/or participants know which group they were assigned to. Third, the 12-week endpoint reflects only short-term recovery, and longer follow-up would be required to determine whether the benefit of CIMT is maintained, diminishes, or equals that of MT and PNF over time, as seen in similar trials conducted in the upper limb. Fourth, because no neurophysiological or neuroimaging studies were performed, differences between groups cannot be definitively attributed to distinct underlying mechanisms and may be due to differences in training specificity alone.

Further trials using functional MRI or other imaging methods, as in mechanism studies of MT, may help determine whether the functional benefit of CIMT is due to distinct patterns of brain reorganization or to targeted training. Lastly, the study did not measure cost-effectiveness or patient-reported quality of life, both of which are important when considering implementation in a real-world, resource-limited rehabilitation setting. Further studies should include multi-center designs with longer follow-up periods, economic analyses, and hybrid or sequential intervention protocols (e.g., CIMT after MT) to better balance the functional advantages of CIMT with the availability and tolerability of MT and PNF.

CONCLUSION

All three interventions (Mirror Therapy, CIMT, and Proprioceptive Neuromuscular Facilitation), plus standard physiotherapy, were shown to produce statistically significant improvements in upper-limb motor function, spasticity, and grip strength in patients with post-stroke upper-limb hemiparesis over 12 weeks. CIMT produced a significantly greater benefit than either Mirror Therapy or PNF in activity level function (ARAT) and similar benefits in motor impairment (FMA-UE), spasticity (MAS), and grip strength. Based on these results, CIMT is more effective in improving functional task performance; however, Mirror Therapy and PNF are effective and well-tolerated when the CIMT's restraint-based protocol is not suitable. Therefore, the choice of adjunct therapy should be based on the individual patient's clinical situation, functional goals, and available clinical resources, and should not be made on the assumption that any one technique is superior.

Author Contributions

Subhan Ali Gondal conceived and designed the study, supervised the research process, and contributed to manuscript drafting. **Aliha Shafqat** assisted in study design, data collection, and data analysis**. Namara Atif** contributed to the literature review, data interpretation, and manuscript preparation. **Saleha Khan** assisted in data collection, manuscript editing, and critical revision. **Aqsa Noreen** contributed to manuscript drafting and final approval of the manuscript. **Nusrat Naseem** supervised the research, provided critical revisions, and approved the final version of the manuscript. All authors reviewed and approved the final manuscript.

Ethical Approval

This study was approved by the Institutional Review Board of Ikram Hospital, Gujrat (IRB No. IKG-002/24) and registered with ClinicalTrials.gov (Registration No. NCT07683130).

Grant Support and Funding Disclosure

None.

Conflict of Interests

None.

REFERENCES

1. Feigin VL, Brainin M, Norrving B, Martins S, Sacco RL, Hacke W, Fisher M, Pandian J, Lindsay P. World Stroke Organization (WSO): global stroke fact sheet 2022. International journal of stroke. 2022 Jan;17(1):18-29. https://doi.org/10.1177/17474930211065917.
2. Vos T, Lim SS, Abbafati C, Abbas KM, Abbasi M, Abbasifard M, Abbasi-Kangevari M, Abbastabar H, Abd-Allah F, Abdelalim A, Abdollahi M. Global burden of 369 diseases and injuries in 204 countries and territories, 1990–2019: a systematic analysis for the Global Burden of Disease Study 2019. The lancet. 2020 Oct 17;396(10258):1204-22. https://doi.org/10.1016/S0140-6736(20)30925-9.
3. Tang Q, Yang X, Sun M, He M, Sa R, Zhang K, Zhu B, Li T. Research trends and hotspots of post-stroke upper limb dysfunction: a bibliometric and visualization analysis. Frontiers in Neurology. 2024 Oct 2;15:1449729. https://doi.org/10.3389/fneur.2024.1449729.
4. Dalton EJ, Jamwal R, Augoustakis L, Hill E, Johns H, Thijs V, Hayward KS. Prevalence of arm weakness, pre-stroke outcomes and other post-stroke impairments using routinely collected clinical data on an acute stroke unit. Neurorehabilitation and Neural Repair. 2024 Feb;38(2):148-60. https://doi.org/10.1177/15459683241229676.
5. O'Flaherty D, Ali K. Recommendations for upper limb motor recovery: an overview of the UK and European rehabilitation after stroke guidelines (2023). InHealthcare 2024 Jul 18 (Vol. 12, No. 14, p. 1433). MDPI. https://doi.org/10.3390/healthcare12141433.
6. Wen X, Li L, Li X, Zha H, Liu Z, Peng Y, Liu X, Liu H, Yang Q, Wang J. Therapeutic role of additional mirror therapy on the recovery of upper extremity motor function after stroke: a single-blind, randomized controlled trial. Neural plasticity. 2022;2022(1):8966920. https://doi.org/10.1155/2022/8966920.
7. Okamura R, Nakashima A, Moriuchi T, Fujiwara K, Ohno K, Higashi T, Tomori K. Effects of a virtual reality-based mirror therapy system on upper extremity rehabilitation after stroke: a systematic review and meta-analysis of randomized controlled trials. Frontiers in neurology. 2024 Jan 8;14:1298291. https://doi.org/10.3389/fneur.2023.1298291.
8. Kim H, Kim J, Jo S, Lee K, Kim J, Song C. Video augmented mirror therapy for upper extremity rehabilitation after stroke: a randomized controlled trial. Journal of Neurology. 2023 Feb;270(2):831-42. https://doi.org/10.1007/s00415-022-11410-6.
9. Saragih ID, Priyanti RP, Batubara SO, Lee BO. Effects of mirror therapy on upper limb motor function of patients with stroke: A systematic review and meta-analysis of randomized controlled trials. Clinical Rehabilitation. 2025 Jan;39(1):23-34. https://doi.org/10.1177/02692155241299211.
10. Alashram AR, Alghwiri AA, Padua E, Annino G. Efficacy of proprioceptive neuromuscular facilitation on spasticity in patients with stroke: A systematic review. Physical Therapy Reviews. 2021 May 4;26(3):168-76. https://doi.org/10.1080/10833196.2021.1892281.
11. Uswatte G, Taub E, Lum P, Brennan D, Barman J, Bowman MH, Taylor A, McKay S, Sloman SB, Morris DM, Mark VW. Tele-rehabilitation of upper-extremity hemiparesis after stroke: Proof-of-concept randomized controlled trial of in-home Constraint-Induced Movement therapy. Restorative Neurology

and Neuroscience. 2021 Sep 20;39(4):303-18. https://doi.org/10.3233/RNN-201100.
12. Hu J, Liu PL, Hua Y, Gao BY, Wang YY, Bai YL, Chen C. Constraint-induced movement therapy enhances AMPA receptor-dependent synaptic plasticity in the ipsilateral hemisphere following ischemic stroke. Neural Regeneration Research. 2020 Aug 24;16(2):319. https://doi.org/10.4103/1673-5374.290900.
13. Ceylan CM, Şen Eİ, Karaagac T, Şahbaz T, Yalıman A. Effect of modified constraint-induced movement therapy on upper extremity function for stroke patients with right/left arm paresis: a single-blind randomized controlled trial. Ahi Evran Medical Journal. 2023 May 1;7(2):155-64. DOI: https://doi.org/10.46332/aemj.1120884.
14. Zhang Y, Xing Y, Li C, Hua Y, Hu J, Wang Y, Ya R, Meng Q, Bai Y. Mirror therapy for unilateral neglect after stroke: A systematic review. European Journal of Neurology. 2022 Jan;29(1):358-71. https://doi.org/10.1111/ene.15122.
15. Hsu HY, Kuo LC, Lin YC, Su FC, Yang TH, Lin CW. Effects of a virtual reality–based mirror therapy program on improving sensorimotor function of hands in chronic stroke patients: a randomized controlled trial. Neurorehabilitation and neural repair. 2022 Jun;36(6):335-45. https://doi.org/10.1177/15459683221081430.
16. Hooria S, Gondal MJ, Kabir A, Mazahir S, Khan A, Kamray R, Mehak S, Imtiaz R. Comparison of Constraint-Induced Movement Therapy vs Mirror Therapy Effect in Infarcted Cerebrovascular Patients for Improving Hand Function: CIMT vs Mirror Therapy for Hand Function in CVA. Journal of Health and Rehabilitation Research. 2024 Sep 6;4(3):1-5. DOI: https://doi.org/10.61919/jhrr.v4i3.1319.
17. Fernández-Solana J, Pardo-Hernández R, González-Bernal JJ, Sánchez-González E, González-Santos J, Soto-Cámara R, Santamaría-Pelaez M. Psychometric properties of the Action Research Arm Test (ARAT) scale in post-stroke patients—Spanish population. International journal of environmental research and public health. 2022 Nov 13;19(22):14918. https://doi.org/10.3390/ijerph192214918.
18. Hervé-Colas J, Newton SP, Engelter ST, Hayward KS, Held JP, Intering N, Kwakkel G, Pohl J, Reisman DS, Schwarz A, Sunnerhagen KS. Standardized international manual of the Fugl-Meyer assessment of motor function after stroke. Neurorehabilitation and neural repair. 2026 Apr;40(4):306-19. https://doi.org/10.1177/15459683251412300.
19. Vidmar T, Goljar Kregar N, Puh U. Reliability of the Modified Ashworth Scale after stroke for 13 muscle groups. Arch Phys Med Rehabil. 2023;104(10):1670-1677. https://doi.org/10.1016/j.apmr.2023.04.008.
20. Leszczak J, Pniak B, Baran J, Guzik A. Reliability of biometric devices for measuring hand grip and finger pinch strength in stroke patients over 50: a prospective observational study. Scientific Reports. 2025 Aug 9;15(1):29188. https://doi.org/10.1038/s41598-025-12712-1.
21. de Sire A, Marotta N, Prestifilippo E, Agostini F, Parente A, Tasselli A, Mezian K, Vecchio M, Longo UG, Ammendolia A. Efficacy of Constraint-Induced Movement Therapy and mirror therapy in improving upper limb motor function and dexterity in post-stroke hemiparetic patients: a randomized controlled trial. La Clinica Terapeutica. 2025 Nov 20;176(6). https://doi.org/10.7417/CT.2025.5288.
22. Tenberg S, Mueller S, Vogt L, Roth C, Happ K, Scherer M, Behringer M, Niederer D. Comparative effectiveness of upper limb exercise interventions in individuals with stroke: a network meta-analysis. Stroke. 2023 Jul;54(7):1839-53. https://doi.org/10.1161/STROKEAHA.123.043110.
23. Saikaley M, Pauli G, Sun H, Serra JR, Iruthayarajah J, Teasell R. Network meta-analysis of non-conventional therapies for improving upper limb motor impairment poststroke. Stroke. 2022 Dec;53(12):3717-27. https://doi.org/10.1161/STROKEAHA.122.040687.
24. Paul J, Yamin T, Rajalakshm G. Comparative Effect of Modified Constraint Induced Movement Therapy, Proprioceptive Training and Task-Oriented Training on Functions of Upper Extremity among Stroke Patient. https://doi.org/10.15621/ijphy/2023/v10i2/1326.
25. Hayward KS, Kramer SF, Dalton EJ, Hughes GR, Brodtmann A, Churilov L, Cloud G, Corbett D, Jolliffe L, Kaffenberger T, Rethnam V. Timing and dose of upper limb motor intervention after stroke: a systematic review. Stroke. 2021 Nov;52(11):3706-17. https://doi.org/10.1161/STROKEAHA.121.034348.
26. Zhang K, Ding L, Wang X, Zhuang J, Tong S, Jia J, Guo X. Evidence of mirror therapy for recruitment of ipsilateral motor pathways in stroke recovery: A resting fMRI study. Neurotherapeutics. 2024 Mar 1;21(2):e00320. https://doi.org/10.1016/j.neurot.2024.e00320.
27. Muñoz-Gómez E, Ingles M, Aguilar-Rodríguez M, Sempere-Rubio N, Mollà-Casanova S, Serra-Añó P. Effects of mirror therapy on spasticity and sensory impairment after stroke: Systematic review and meta-analysis. PM&R. 2023 Nov;15(11):1478-92. https://doi.org/10.1002/pmrj.12964.