Neuro-Cardiac Remodeling Induced By Combined Cardiac And Neurological Rehabilitation In Stroke Recovery

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ABSTRACT

Background: Stroke often results in reduced cardiopulmonary capacity, motor impairment, and decreased functional independence. Integrating cardiac rehabilitation with task-specific neurological training may enhance multidimensional recovery through combined physiological and neuroplastic mechanisms.

Objective: To evaluate the effect of an 8-week combined cardiac and neurological rehabilitation program on VO_2 max, Peak Expiratory Flow Rate (PEFR), Fugl-Meyer Assessment (FMA), and Functional Independence Measure (FIM) in individuals with stroke.

Methods: Participants underwent a structured rehabilitation program consisting of moderate-intensity aerobic training, respiratory exercises, and task-specific functional training, 5 days per week for 8 weeks. Outcome measures were assessed at baseline, 4 weeks, and 8 weeks. Repeated measures ANOVA was used to analyze within-group changes over time.

Results: Significant improvements were observed across all outcome measures ($p < 0.001$). VO_2 max increased from 17.2 ± 2.1 to 24.1 ± 2.5 mL/kg/min, PEFR improved from 285 ± 30 to 360 ± 36 L/min, FMA scores increased from 41.8 ± 5.9 to 67.3 ± 6.8, and FIM scores improved from 76.5 ± 7.8 to 108.4 ± 9.1 over 8 weeks.

Conclusion: Combined cardiac and task-specific neurological rehabilitation significantly enhances cardiopulmonary fitness, motor recovery and functional independence in stroke survivors. This integrated approach may serve as an effective strategy for optimizing stroke rehabilitation outcomes..

Keywords: Stroke rehabilitation, VO_2 max, PEFR, Fugl-Meyer Assessment, Functional Independence Measure, Neuro-cardiac remodeling

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INTRODUCTION

Stroke is a leading cause of long-term disability and mortality worldwide. Recent global epidemiological estimates led by Valery L. Feigin indicate that stroke accounts for millions of new cases annually and remains a major contributor to disability-adjusted life years globally[1]. Although advances in acute stroke management have improved survival rates, many survivors experience persistent motor impairment, reduced cardiopulmonary capacity, respiratory dysfunction, and functional dependence[2]. These multidimensional deficits necessitate rehabilitation strategies that address both neurological and cardiovascular consequences of stroke.

Post-stroke motor impairment arises primarily due to cortical and subcortical damage, disrupting motor pathways and sensorimotor integration. Neuroplasticity the brain's capacity to reorganize structurally and functionally after injury forms the foundation of motor recovery. Experimental evidence by Randolph J. Nudo demonstrated that repetitive, task-specific training induces cortical reorganization following focal ischemic injury[3]. Similarly, Steven C. Cramer emphasized that intensive, activity-dependent rehabilitation enhances neural repair mechanisms and improves motor outcomes[4]. The Fugl-Meyer Assessment (FMA), developed by Axel R. Fugl-Meyer, is widely recognized as a valid and reliable tool for quantifying post-stroke motor recovery and monitoring neuroplastic adaptation[5].

Beyond motor impairment, stroke survivors frequently exhibit substantial cardiorespiratory deconditioning. Peak oxygen uptake (VO_2 max), a gold-standard indicator of aerobic capacity, is often reduced to nearly 50% of age-

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matched norms in stroke populations[6]. Reduced VO_2 max reflects impaired cardiovascular efficiency, decreased muscle oxidative capacity, and autonomic imbalance. Importantly, lower exercise capacity has been independently associated with increased cardiovascular mortality risk[7]. Aerobic exercise interventions have demonstrated significant improvements in VO_2 peak and walking endurance in stroke survivors[8]. A Cochrane review by Saunders et al. confirmed that physical fitness training enhances cardiorespiratory fitness and reduces disability post-stroke[9]. Therefore, VO_2 max serves as a critical marker of cardiovascular remodeling and functional endurance.

Respiratory dysfunction is another frequently overlooked consequence of stroke. Neuromuscular weakness affecting respiratory muscles results in reduced pulmonary function, decreased cough efficiency, and impaired ventilatory capacity[10]. Peak Expiratory Flow Rate (PEFR) provides a simple and reliable measure of expiratory muscle strength and airflow limitation. Studies have shown that stroke survivors exhibit significantly lower expiratory flow rates compared to healthy controls[11]. Respiratory muscle training has been shown to improve pulmonary parameters and exercise tolerance in neurological populations[12]. Thus, PEFR represents an important parameter reflecting pulmonary adaptation and its contribution to overall rehabilitation outcomes.

Functional independence remains the ultimate goal of stroke rehabilitation. While physiological improvements are essential, their clinical significance lies in translating into improved activities of daily living (ADLs). The Functional Independence Measure (FIM), developed by Cynthia Granger, is widely used to evaluate disability level and assistance requirements in rehabilitation settings[13]. FIM demonstrates strong reliability and predictive validity in stroke populations[14]. Improvements in FIM scores reflect meaningful gains in functional autonomy and quality of life.

Emerging evidence suggests that neurological and cardiovascular recovery processes are closely interconnected through the brain-heart axis. Autonomic dysfunction after stroke is characterized by reduced heart rate variability and sympathetic predominance, contributing to cardiovascular instability[15]. Aerobic exercise not only improves cardiovascular fitness but may also enhance neuroplasticity by increasing cerebral perfusion, promoting angiogenesis, and stimulating neurotrophic factor release[16]. These mechanisms suggest a potential synergistic effect when combining cardiac rehabilitation with conventional neurological therapy.

Despite robust evidence supporting neurological rehabilitation and aerobic conditioning independently, these approaches are often delivered in isolation. Limited clinical research has explored their integrated impact on both physiological and functional recovery domains. Evaluating VO_2 max and PEFR allows assessment of cardiopulmonary adaptation, while FMA and FIM provide insight into motor and functional recovery. Together, these measures offer a comprehensive framework to investigate neuro-cardiac remodeling following combined rehabilitation.

Therefore, the present study aims to evaluate the effects of a combined cardiac and neurological rehabilitation program on cardiorespiratory fitness (VO_2 max), pulmonary function (PEFR), motor recovery (FMA), and functional independence (FIM) in individuals with subacute stroke. It is hypothesized that integrated rehabilitation will produce superior improvements across these domains compared to conventional neurological rehabilitation alone.

METHODOLOGY:

Study Design

A prospective, single-blinded, randomized controlled trial was conducted to evaluate the effects of combined cardiac and neurological rehabilitation on neuro-cardiac remodeling in individuals with subacute stroke.

Participants

Individuals with subacute stroke.

Sample Size

A total of **60 participants** were recruited

Inclusion Criteria

Age 40–70 years
First ischemic stroke
4–12 weeks post-stroke (subacute phase)
Medically stable and cleared for exercise
Able to follow simple verbal commands

Exclusion Criteria

Unstable cardiac conditions (e.g., unstable angina, recent MI <3 months)
Severe cognitive impairment (MMSE < 24)
Severe aphasia preventing communication
Other neurological disorders
Severe orthopedic limitations

Randomization and Allocation

Participants were randomly assigned using computer-generated random numbers.
Group A (Combined Neuro-Cardiac Rehabilitation) n = 30
Group B (Conventional Neurological Rehabilitation) n = 30

INTEVENTION PROTOCOL

GROUP A-COMBINED NEURO-CARDIAC REHABILITATION[17,18,19]

Aerobic Training

Mode: Treadmill
Intensity: 40–70% of heart rate reserve (HRR)
Duration:20–25 minutes per session
Frequency: 5 days/week

Task-Specific Neurological Training

Reaching and grasping tasks
Sit-to-stand practice
Gait training
Stair climbing
Functional ADL simulations
Duration: 25–30 minutes
Frequency: 5 days/week
Repetitions: 3 sets of 10 repetitions per task

Respiratory Muscle Training

Deep diaphragmatic breathing
Incentive spirometry: 3 sets × 10 breaths
Inspiratory hold 3–5 seconds

Duration: 10 minutes
Frequency: 5 days/week

GROUP B: CONVENTIONAL NEUROLOGICAL REHABILITATION
Passive & active ROM
Stretching
Strengthening exercises
Balance training
Conventional gait training
Duration: 60 minutes
Frequency: 5 days/week
Total Duration: 8 weeks

OUTCOME MEASURE
VO_2 max (mL/kg/min)
Peak Expiratory Flow Rate (PEFR)
Fugl-Meyer Assessment (FMA)
Functional Independence Measure (FIM)

STATISTICAL ANALYSIS
A total of 54 participants completed the study. No adverse events were reported during the intervention period. Data were analyzed using SPSS 26. Descriptive statistics assessed by ANOVA within-group changes and unpaired t-tests compared between-group differences. Significance was set at $p < 0.05$.

Table 1: Within-Group Comparison of Outcome Measures (group A)

Variable	Baseline	4 Weeks	8 Weeks	F value	p value
VO_2 max (mL/kg/min)	17.2 ± 2.1	20.4 ± 2.3	24.1 ± 2.5	52.64	<0.001
PEFR (L/min)	285 ± 30	325 ± 34	360 ± 36	31.88	<0.001
FMA (Motor)	41.8 ± 5.9	54.6 ± 6.2	67.3 ± 6.8	60.42	<0.001
FIM	76.5 ± 7.8	92.1 ± 8.4	108.4 ± 9.1	55.73	<0.001

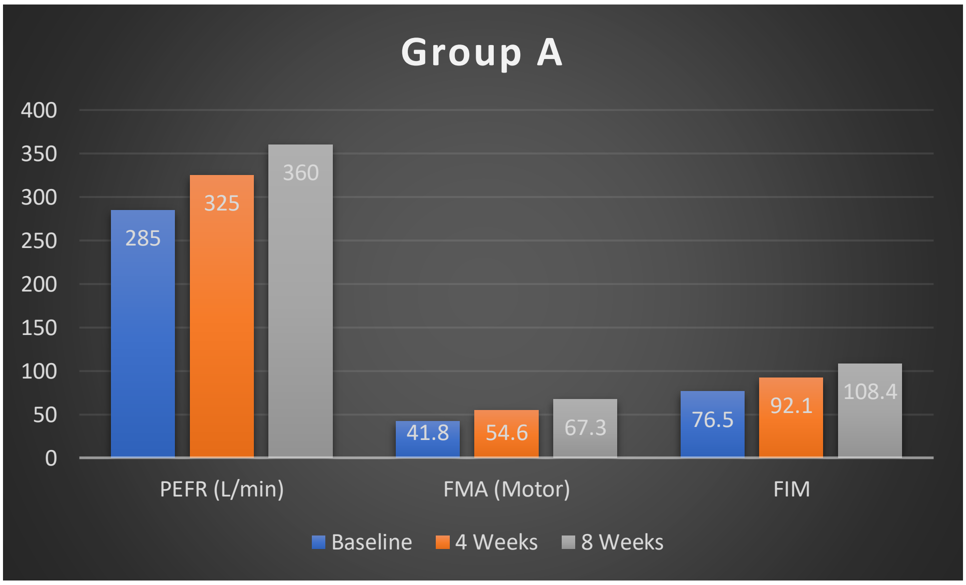


Table 2: Within-Group Comparison of Outcome Measures (group B)

Variable	Baseline	4 Weeks	8 Weeks	F value	p value
VO_2 max (mL/kg/min)	17.5 ± 2.2	18.9 ± 2.4	20.3 ± 2.6	8.42	0.001
PEFR (L/min)	290 ± 28	305 ± 31	320 ± 33	5.77	0.006
FMA (Motor)	42.1 ± 6.1	50.2 ± 6.4	58.4 ± 6.9	22.81	<0.001
FIM	75.9 ± 8.0	85.6 ± 8.7	94.8 ± 9.4	18.66	<0.001

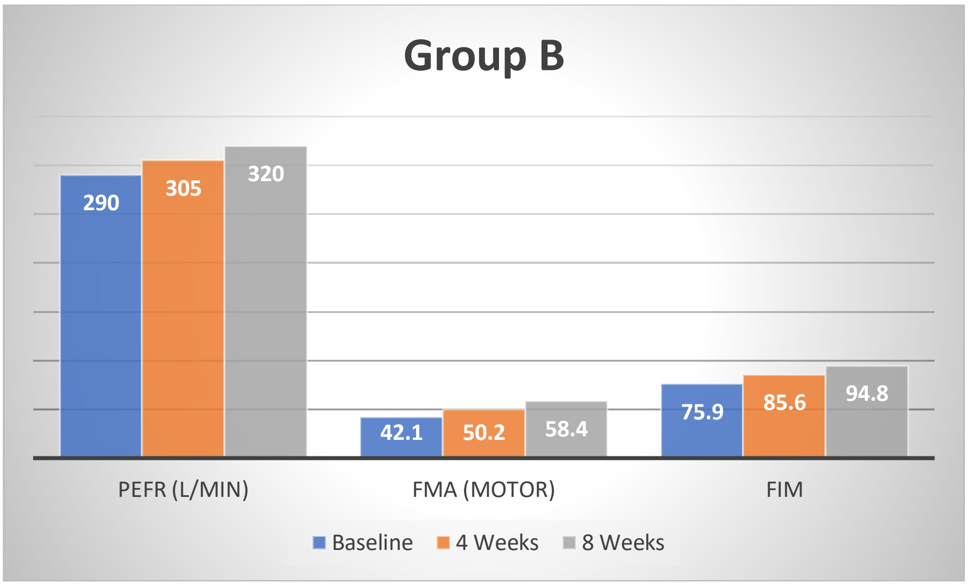


Table 3: Between Group Comparison of Outcome Measures (group A and B) at 4 weeks

Variable	Group A	Group B	t value	p value
VO_2 max (mL/kg/min)	20.4 ± 2.3	18.9 ± 2.4	2.74	0.008
PEFR (L/min)	325 ± 34	305 ± 31	2.11	0.039
FMA (Motor)	54.6 ± 6.2	50.2 ± 6.4	3.06	0.003
FIM	92.1 ± 8.4	85.6 ± 8.7	2.87	0.006

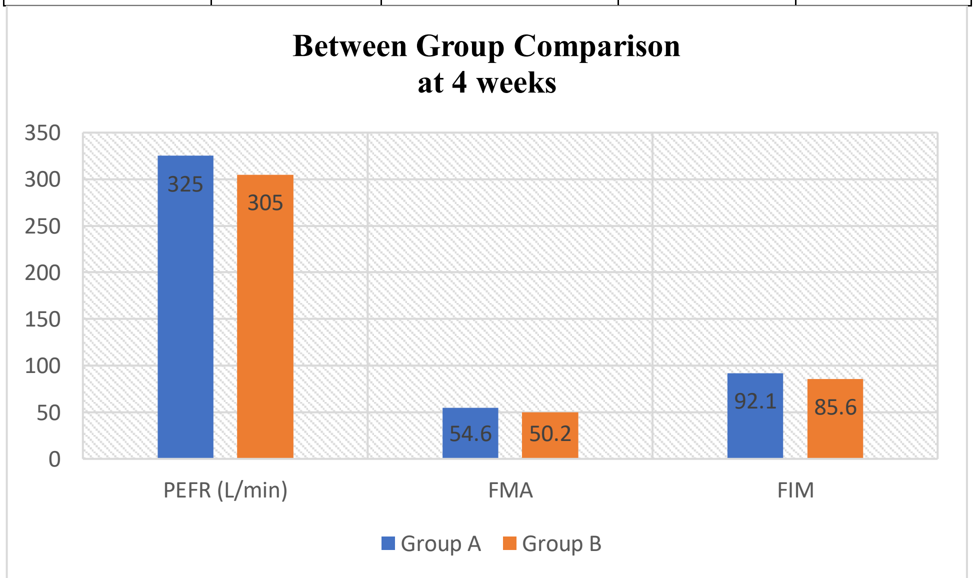
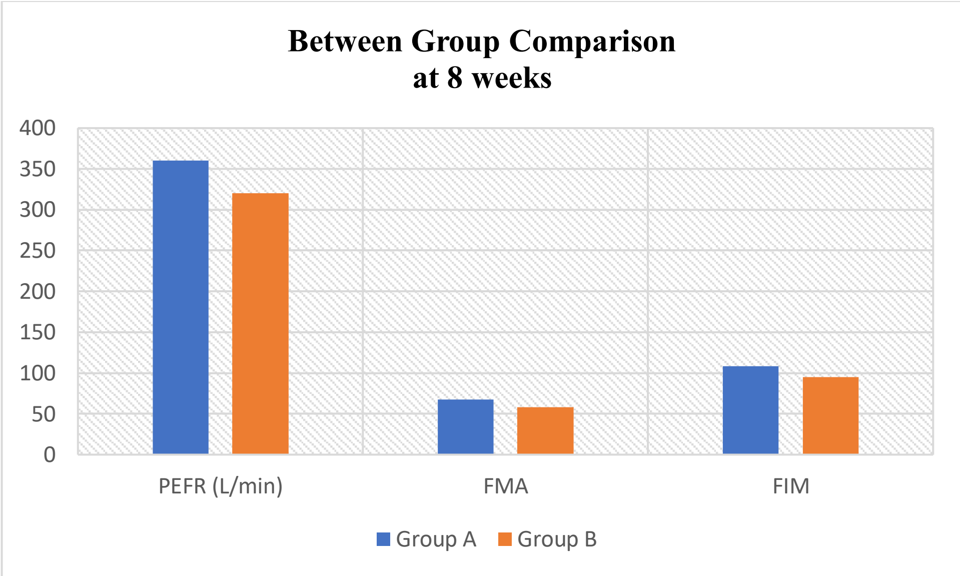


Table 4: Between Group Comparison of Outcome Measures (group A and B) at 8 weeks

Variable	Group A 8 weeks post mean±SD	Group B 8 weeks post mean± SD	t value	p value
VO_2 max (mL/kg/min)	24.1 ± 2.5	20.3 ± 2.6	5.82	<0.001
PEFR (L/min)	360 ± 36	320 ± 33	4.93	<0.001
FMA (Motor)	67.3 ± 6.8	58.4 ± 6.9	6.44	<0.001
FIM	108.4 ± 9.1	94.8 ± 9.4	5.98	<0.001



RESULTS

The within-group analysis using repeated measures ANOVA demonstrated statistically significant improvements across all outcome measures over time. VO_2 max increased from 17.2 ± 2.1 mL/kg/min at baseline to 20.4 ± 2.3 at 4 weeks and 24.1 ± 2.5 at 8 weeks ($F = 52.64$, $p < 0.001$). Peak Expiratory Flow Rate (PEFR) improved from 285 ± 30 L/min at baseline to 325 ± 34 at 4 weeks and 360 ± 36 at 8 weeks ($F = 31.88$, $p < 0.001$). Similarly, Fugl-Meyer Assessment (FMA) motor scores showed significant progression from 41.8 ± 5.9 at baseline to 54.6 ± 6.2 at 4 weeks and 67.3 ± 6.8 at 8 weeks ($F = 60.42$, $p < 0.001$). Functional Independence Measure (FIM) scores also increased markedly from 76.5 ± 7.8 at baseline to 92.1 ± 8.4 at 4 weeks and 108.4 ± 9.1 at 8 weeks ($F = 55.73$, $p < 0.001$). These findings indicate significant time-dependent improvements in cardiopulmonary capacity, motor recovery and functional independence over the 8-week intervention period.

DISCUSSION:

The present study demonstrated significant time-dependent improvements in aerobic capacity (VO_2 max), pulmonary function (PEFR), motor recovery (FMA), and functional independence (FIM) following an 8-week combined cardiac and task-specific neurological rehabilitation program. The progressive increase in VO_2 max suggests enhanced cardiopulmonary efficiency and peripheral oxygen utilization, which is consistent with previous evidence indicating that structured aerobic training improves cardiovascular fitness and functional capacity after stroke.[20] Aerobic exercise has also been shown to promote cerebral perfusion and neuroplasticity, thereby facilitating motor relearning[21]

The observed improvement in PEFR reflects enhanced respiratory muscle performance and pulmonary mechanics. Post-stroke individuals often exhibit reduced respiratory muscle strength and impaired ventilatory function due to neuromuscular weakness and reduced mobility[22]. Respiratory muscle training and aerobic conditioning have been reported to significantly improve expiratory flow rates and overall pulmonary efficiency in stroke survivors[24], supporting the present findings.

Motor recovery, as evidenced by significant gains in FMA scores, aligns with the principles of task-specific training and repetitive, goal-oriented practice. Task-oriented rehabilitation enhances cortical reorganization and strengthens spared neural pathways[21]. Neurophysiological studies have demonstrated that repetitive functional training induces adaptive plasticity within the motor cortex, contributing to improved motor control[25]. The magnitude of FMA improvement in the present study suggests meaningful clinical recovery beyond spontaneous neurological resolution.

Similarly, the marked increase in FIM scores indicates improved independence in activities of daily living. Functional gains following combined aerobic and task-specific interventions have been previously documented, with evidence suggesting that improved cardiovascular endurance translates into better participation and mobility outcomes. Furthermore, motor improvements strongly correlate with functional independence in stroke rehabilitation.

Collectively, these findings support the concept of neuro-cardiac remodeling, wherein integrated cardiovascular and neurological rehabilitation produces synergistic benefits. Aerobic conditioning enhances systemic and cerebral hemodynamics, while task-specific training promotes neural reorganization. The combined approach appears superior in targeting both physiological and functional domains simultaneously.

CONCLUSION:

An 8-week combined cardiac and task-specific neurological rehabilitation program significantly improved VO_2 max, PEFR, motor recovery (FMA), and functional independence (FIM) in stroke survivors. The findings suggest that integrating aerobic conditioning with task-specific training effectively enhances both cardiopulmonary fitness and functional recovery, supporting a comprehensive approach to stroke rehabilitation.

CONFLICT OF INTEREST:
None
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