Journal of Current Science and Technology, January-March 2026 Vol. 16 No. 1, Article 152

ISSN 2630-0656 (Online)

Cite this article: Chondaen, N., Isariyapan, O., Kerdsawatmongkon, J., Chinda, K., Sangthong, B., Roongpiboonsopit, D., Chotimol, P., & Srisoparb, W. (2026). Potential benefits of boxing training on attenuating arterial stiffness, heart rate variability and motor functioning in chronic ischemic stroke survivors. *Journal of Current Science and Technology*, *16*(1), Article 152. https://doi.org/10.59796/jcst.V16N1.2026.152

Journal of Current Science and Technology

Journal homepage: https://jcst.rsu.ac.th

Potential Benefits of Boxing Training on Attenuating Arterial Stiffness, Heart Rate Variability and Motor Functioning in Chronic Ischemic Stroke Survivors

Natchaya Chondaen[1], Olan Isariyapan[1,2], Jeerawan Kerdsawatmongkon[1], Kroekkiat Chinda[3], Benjarat Sangthong[4], Duangnapa Roongpiboonsopit[5], Phatiwat Chotimol[6,7], and Waroonnapa Srisoparb[1,2,*]

[1]Exercise and rehabilitation sciences research unit, Department of Physical Therapy, Faculty of Allied Health Sciences, Naresuan University, Phitsanulok 65000, Thailand
[2]Department of Physical Therapy, Faculty of Allied Health Sciences, Naresuan University, Phitsanulok 65000, Thailand
[3]Department of Physiology, Faculty of Medical Science, Naresuan University, Phitsanulok 65000, Thailand
[4]Faculty of Physical Therapy and Sports Medicine, Rangsit University, Pathum Thani 12000, Thailand
[5]Division of Neurology, Department of Medicine, Faculty of Medical, Naresuan University, Phitsanulok 65000, Thailand
[6]Department of Cardio-Thoracic Technology, Faculty of Allied Health Sciences, Naresuan University, Phitsanulok 65000, Thailand
[7]Interdisciplinary Health and Data Sciences research unit (IHaDS), Department of Cardio-Thoracic Technology, Faculty of Allied Health Sciences, Naresuan University, Phitsanulok 65000, Thailand

*Corresponding author; E-mail: waroonnapas@nu.ac.th

Received 26 May 2025; Revised 17 July 2025; Accepted 25 July 2025; Published online 20 December 2025

Abstract

Aerobic exercise has demonstrated benefits in improving arterial stiffness, cardiovascular autonomic function, and motor performance in individuals with stroke. While exergames such as the Wii boxing game have shown potential to enhance cardiovascular fitness, their accessibility may be limited due to technological or equipment constraints. As an alternative, a home-based boxing program may serve as a practical intervention to improve atherosclerosis-related outcomes and autonomic nervous system function in stroke survivors. This study aimed to investigate the effects of moderate-intensity boxing training on arterial stiffness, arterial obstruction, autonomic function, and motor impairments in individuals with chronic ischemic stroke. This study employed a single-cohort feasibility design and was conducted in a community-based setting in Mueang District, Phitsanulok, Thailand. It involved 12 stroke survivors with a mean post-stroke duration of 25.4 months. Participants engaged in 24 one-hour boxing sessions over an 8-week period. Outcome measures included the Cardio-Ankle Vascular Index (CAVI), Ankle-Brachial Index (ABI), Heart Rate Variability (HRV), and Fugl-Meyer Assessment (FMA), evaluated at baseline, 4 weeks, and 8 weeks. Significant improvements were observed in CAVI values on both sides, with reductions from 9.55 to 8.45 (right) and from 9.30 to 8.60 (left) ($p = 0.001$). HRV analysis showed enhanced autonomic function, with increases in LFnu from 32.75 to 41.96 and LF/HF ratio from 0.51 to 0.99 ($p = 0.017$). Motor performance, as measured by the FMA, significantly improved from 80 to 96 ($p = 0.001$), while ABI values remained unchanged. These findings suggest that an accessible, moderate-intensity boxing program may be an effective strategy for supporting vascular health, autonomic regulation, and motor recovery in chronic stroke rehabilitation.

Keywords**:** *boxing; stroke; vascular stiffness; autonomic nervous system; motor skills*

1. Introduction

Atherosclerosis has a higher prevalence among individuals with chronic ischemic stroke than among healthy individuals (Suzuki et al., 2013). Previous studies have demonstrated that ischemic stroke patients with atherosclerosis and autonomic cardiac dysfunction have an increased risk of recurrent stroke (Su et al., 2017). Consequently, post-stroke, patients may develop autonomic nervous dysfunction, potentially leading to abnormal heart function and thereby increasing the risks of disability and mortality (Chen et al., 2017). Moreover, the enduring physical disability and persistent disruption of heart function following stroke highlight the chronic burden experienced throughout a patient's lifetime (Feigin et al., 2021).

Aerobic exercise administered to stroke patients has the potential to improve arterial stiffness (Zhang et al., 2022), cardiac autonomic nervous system function (Raimundo et al., 2021), and motor system (Zhang et al., 2020). Alternative forms of aerobic exercise have gained popularity as a contemporary rehabilitation approaches for stroke patients. The Wii boxing game shows a greater capacity to enhance cardiovascular fitness than Wii-bowling, Wii-baseball and Wii-tennis (Trinh et al., 2016). However, game integrated technology may have limitations on accessibility. A prior study has employed boxing training as part of stroke rehabilitation without the use of game technology. The boxing training program has demonstrated noticeable enhancements in stroke patients' balance, upper limb activities, walking ability, and overall quality of life (Park et al., 2017). Furthermore, the home-based boxing training program for individuals with chronic stroke exhibited notable improvements in trunk performance, balance, and a reduction in the fear of falling. Notably, patients also reported considerable enjoyment from the boxing training program (Kerdsawatmongkon et al., 2023). These findings suggest that boxing training may serve as a potential alternative home-based exercise regimen for stroke patients. However, a research gap remains regarding the effects of boxing training on atherosclerosis and autonomic cardiac regulation in stroke patients.

The Cardio-Ankle Vascular Index (CAVI) and the Ankle Brachial Index (ABI) are both widely used, non-invasive methods for assessing arterial properties (Khan et al., 2008; Shirai et al., 2011). CAVI measures the overall stiffness of arteries from the origin of the aorta to the ankle (Suzuki et al., 2013), offering a straightforward and reproducible assessment that is independent of blood pressure variations (Shirai et al., 2006). Meanwhile, ABI demonstrates high specificity and sensitivity in detecting arterial stenosis or obstruction (Hong et al., 2016; Lee et al., 2016).

Heart rate variability (HRV) refers to the variation in time intervals between consecutive heartbeats. It is controlled by the sympathetic and parasympathetic branches of the autonomic nervous system (Shaffer & Ginsberg, 2017). HRV is associated with cardiovascular disease, as previous studies indicated that low HRV in healthy individuals is correlated with an elevated long-term risk of atrial fibrillation, major adverse cardiac events, stroke, and mortality (Orini et al., 2023). Research findings suggest that the HRV of acute ischemic stroke patients significantly declines in comparison to that of healthy controls (Korpelainen et al., 1996). Furthermore, previous research has demonstrated that individuals with acute ischemic stroke exhibit lower levels of low frequency (LF) and high-frequency (HF) components, including normalized LF, normalized HF, and the LF/HF ratio when compared to their healthy counterparts (Chen et al., 2013).

Based on the evidence presented, stroke survivors often experience arterial stiffness, impaired autonomic cardiac regulation, and motor dysfunction, all of which reduce quality of life and increase cardiovascular risk. Aerobic exercise has been shown to improve vascular health, autonomic function, and motor performance; however, technology-based programs like exergaming may have limited accessibility. Boxing training offers a practical, rhythm-based aerobic activity that can be performed in community or home settings, potentially addressing these limitations. It is hypothesized that community-based boxing training is a feasible and effective intervention to improve cardiovascular function and motor performance in stroke survivors.

2. Objectives

To investigate the effects of boxing training on arterial stiffness (AS), arterial obstruction, cardiovascular autonomic function, and motor impairments in individuals with chronic ischemic stroke.

3. Materials and Methods

3.1 Study Design and Setting

This was a single-cohort feasibility study, with all training sessions and outcome measurements conducted in the participants' homes in the Mueang

district of Phitsanulok, Thailand. Ethical approval was granted by the Naresuan University Institutional Review Board (IRB No. 0011/62), the Buddhachinaraj Hospital Institutional Review Board (IRB No. 101/62), and the Thai Clinical Trial Registration (TCTR20200114002).

3.2 Participants

The sample size was determined based on recommendations for a pilot feasibility study, which suggest a minimum of 12 participants (Julious, 2005). A total of 12 individuals with chronic ischemic stroke in Mueang District, Phitsanulok, Thailand was recruited. Inclusion criteria were: age 40–75 years; first-ever ischemic stroke within the past 6 months to 5 years; ability to stand independently for more than 5 minutes; ability to follow a two-step command; and a score above the cognitive impairment cut-off on the Mini-Mental State Examination Thai Version 2002 (MMSE-Thai 2002), defined as ≥14 for individuals with no formal education, ≥17 for those with primary education, and ≥22 for those with secondary education or higher (Thai Cognitive Test Development Committee, 2002). Exclusion criteria were: musculoskeletal conditions limiting arm movement; bilateral hemiparetic stroke; severe spasticity of the shoulder adductors, elbow flexors, or wrist flexors (Modified Ashworth Scale ≥3); motor recovery score of the upper extremity ≤18 on the Fugl-Meyer Assessment (FMA); high risk of falling (Short Form of the Berg Balance Scale <10); atrial fibrillation; resting heart rate >85% of age-predicted maximum heart rate; and participation in other rehabilitation or relaxation programs during the intervention period.

3.3 Boxing Training Program

The physiotherapist served as boxing trainer, guiding participants in achieving proper boxing posture, providing motivation to help them reach their training objectives, closely monitoring heart rate data, adjusting the training program's progression as needed, and documenting any incidents or observations during and after each session.

The boxing training regimen began with a thorough warm-up. This included a 5-minute session of dynamic stretching exercises followed by 5 minutes of air punching. Participants then began boxing either in a seated or standing position, depending on their individual capabilities. The punching target was positioned within the reachable range of the affected arm. Training began with a jab punch, followed by hook punch and uppercut punch, executed first on the sound side and then on the affected side. Each punch was repeated on both sides, aiming for at least 30 punches within a 3-minute set or as tolerated by the participant. There was a 1-minute rest interval between sets, or longer if needed for the participant to continue. Participants were required to maintain moderate-intensity exercise, defined as 40–60% of heart rate (HR) reserve or a rating of perceived exertion (RPE) of 11–16 throughout the session. The progressive training program consisted of 40–50% HR reserve for 32 minutes during weeks 1–4, and 50–60% HR reserve for 32–40 minutes during weeks 5–8. Lastly, the cool-down consisted of stretching exercises, holding each position for 15–30 seconds, resting for 30 seconds, and performing slow diaphragmatic breathing (Billinger et al., 2014). The training program comprised 50–60 minute sessions conducted three times per week, for a total of 24 sessions over 8 weeks. Throughout the training period, participants did not receive any additional rehabilitation, ensuring that observed outcomes could be attributed to the boxing program.

Participants were considered dropouts if they experienced chest pain; uncontrolled heart rate or blood pressure (exceeding 120 beats per minute or 220/110 mmHg); wheezing; loss of balance; attended fewer than 24 sessions; or failed to maintain an exercise intensity of at least 40–50% of their heart rate reserve during training.

3.4 Assessment Tools

Arterial stiffness, arterial obstruction, cardiovascular autonomic function, motor impairments, and degree of disability were measured using CAVI, ABI, HRV, and FMA, respectively. Furthermore, participant's compliance with the training program and the occurrence of any adverse events during or after the training were recorded. Assessments were conducted at baseline (prior to the first training session), mid-intervention (at 4 weeks on a non-training day), and post-intervention (within 24–48 hours after the final session) by two experienced physical therapists who were independent of the boxing trainer. One assessor evaluated CAVI, ABI, and HRV, while the other assessed FMA. Both assessors demonstrated excellent intra-rater reliability across all measurements.

3.4.1 Cardio-Ankle Vascular Index (CAVI) and Ankle Brachial Index (ABI)

The vascular screening equipment VaSera1500 (Fukuda Denshi Co. Ltd, Tokyo) was used to measure both CAVI and ABI. A CAVI value of 9.0 or higher indicates suspected arteriosclerosis, while values between 8.0 and 9.0 are classified as "borderline." Conversely, a CAVI below 8.0 is considered within the normal range (Sun, 2013). The ABI was used to assess blood flow in the brachial artery, dorsalis pedis artery, and posterior tibial artery (McClary & Massey, 2025). The ABI ranging from 0.4 to 0.9 indicates mild to moderate peripheral artery disease (PAD), while an ABI below 0.40 suggests severe PAD. Additionally, an ABI exceeding 1.3 is considered abnormal and indicates non-compressible vessels (Khan et al., 2008).

3.4.2 Heart Rate Variability (HRV)

Cardiovascular autonomic function was evaluated by HRV using PowerLab-LabChart7 software. A 5-minute electrocardiogram (ECG) recording was obtained during a 20-minute supine resting period. This short-term ECG recording can detect pathological changes in autonomic nervous system function (Kleiger et al., 2005). HRV is defined as fluctuations in the intervals between normal heartbeats and was calculated using the frequency domain method. High-frequency (HF) power represents cardiac parasympathetic activity, while low-frequency (LF) power represents parasympathetic-sympathetic balance. The LF/HF ratio was calculated to determine sympathovagal balance (Sztajzel, 2004).

3.4.3 Fugl Meyer Scale (FMA)

The FMA was used to evaluate motor impairment in stroke patients. It is scored based on direct observation of the patient's performance and has demonstrated good concurrent validity and test-retest reliability (Alt Murphy et al., 2015). The motor functioning section of the FMA scoring system ranges from 0 to 100 points, with 0 representing hemiplegia and 100 indicating normal motor performance. This breakdown allocates 66 points for assessing the upper extremities and 34 points for evaluating the lower extremities (Gladstone et al., 2002).

3.4.4 Recording of Adverse Events

Muscle soreness, fatigue, delayed onset muscle soreness, muscle cramps, musculoskeletal injuries and falls were documented within 8–24 hours after each boxing session.

3.5 Statistical Analysis

Participant characteristics were examined using the Shapiro-Wilk test. The participants' characteristic data were reported as means ± standard deviation or as frequencies with corresponding percentages. CAVI, ABI, HRV, and FMA data were presented as medians with interquartile ranges. Friedman test, followed by the Wilcoxon signed-rank test, was used to examine the differences in CAVI, ABI, HRV, and FMA before and after training. All statistical analyses were conducted using SPSS version 17.

4. Results

4.1 Flow of Participants through the Trial

A total of 163 individuals with chronic stroke were assessed for eligibility, of whom 149 were excluded for not meeting the inclusion criteria. Fourteen individuals with stroke were recruited for the study. Two declined to participate in the training program, leaving twelve participants who completed the 8-week boxing training intervention (Figure 1).

4.2 Compliance with Trial Method

All 12 participants received one hour of boxing training three days per week for eight weeks. After the boxing program, two participants experienced adverse events, including shoulder and wrist pain. However, these discomforts were quickly relieved by applying a cold compress after training and allowing one night of rest. The baseline characteristics of the 12 participants are presented in Table 1.

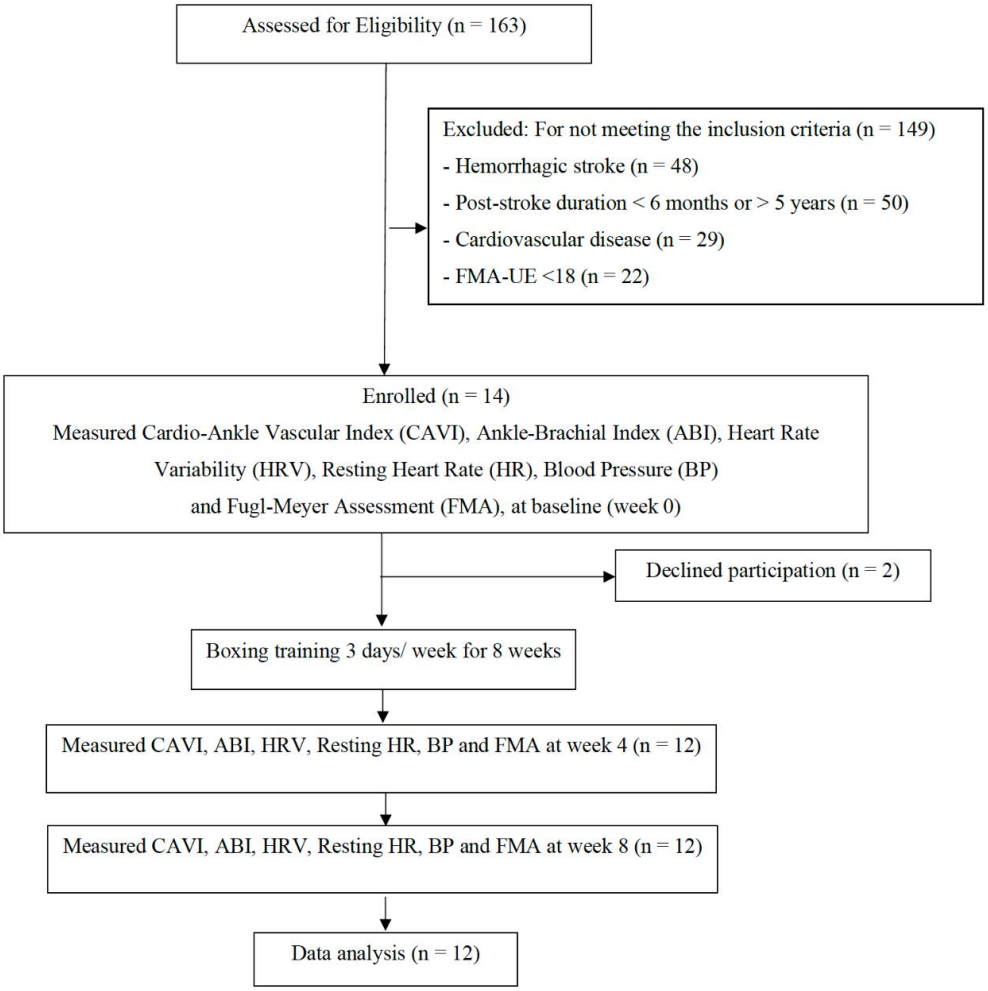

Figure 1 Flowchart of participant recruitment, allocation, and completion of the 8-week boxing training program

Table 1 Baseline characteristics of participants (n = 12)

Characteristics	n = 12
Sex, males, *n* (%)	5 (41.7)
Age, years, mean (SD)	63.4 (4.6)
Handedness, right, *n* (%)	8 (66.7)
Time since stroke, months, mean (SD)	27.5 (22.7)
Hemiparesis, *n* right (%)	9 (75.0)
Short Form Berg Balance Scale (28), mean (SD)	18.2 (3.6)
Modified Rankin Scale	
Grade 0	5 (41.7)
Grade 1	2 (16.7)
Grade 2	4 (33.3)
Grade 3	1 (8.3)
Medication	
Enalapril (angiotensin-converting enzyme inhibitor, n (%))	4 (33.3)
Aspirin, n (%)	9 (75.0)
Metformin, n (%)	4 (33.3)
Amlodipine (calcium channel blocker), n (%)	5 (41.7)
Statin, n (%)	10 (83.3)

Table 2 Outcome measurements at baseline, week 4, and week 8 of the training program (n = 12)

Outcome Measures	Median (IQR1, 3)			Pairwise Comparison (Wilcoxon signed-rank test) *p*-value			Friedman test *p*-value (effect size; Kendall's W)
	Baseline (week 0)	Week 4	Week 8	week 4 compared with baseline (effect size; r)	week 8 compared with baseline (effect size; r)	week 8 compared with week 4 (effect size; r)	
CAVI (Rt.)	9.55 (8.80, 10.35)	**9.00 (8.40, 9.85)**	**8.45 (8.10, 9.05)**	0.066 (0.53)	**0.001 (1.00)***	**0.006 (0.80)***	**0.001 (0.91)****
CAVI (Lt.)	9.30 (8.93, 10.08)	**9.05 (8.60, 10.08)**	**8.60 (7.98, 9.10)**	0.262 (0.32)	**0.001 (1.00)***	**0.019 (0.68)***	**0.001 (0.63)****
ABI (Rt.)	1.08 (1.05, 1.16)	1.06 (1.030, 1.100)	1.05 (1.01, 1.10)	N/A	N/A	N/A	0.344 (0.09)
ABI (Lt.)	1.02 (0.97, 1.08)	1.07 (1.01, 1.12)	1.07 (1.01, 1.10)	N/A	N/A	N/A	0.336 (0.09)
LF ms²	111.22 (93.28, 261.58)	98.65 (68.82, 331.31)	262.11 (83.00, 316.60)	N/A	N/A	N/A	0.558 (0.05)
LF nu*	32.75 (24.00, 37.18)	**41.00 (32.97, 45.23)**	**41.96 (39.89, 47.80)**	**0.041 (0.59)***	**0.004 (0.83)***	0.414 (0.24)	**0.013 (0.36)****
HF ms²	225.54 (97.45, 454.40)	145.58 (70.29, 403.33)	250.30 (90.45, 305.05)	N/A	N/A	N/A	0.779 (0.02)
HF nu	56.86 (43.38, 66.47)	47.80 (41.48, 52.71)	44.22 (40.26, 48.00)	N/A	N/A	N/A	0.076 (0.22)
LF/HF ratio	0.51 (0.41, 0.81)	**0.85 (0.69, 1.07)**	**0.99 (0.90, 1.05)**	**0.025 (0.65)***	**0.008 (0.77)***	0.683 (0.12)	**0.017 (0.34)****
Resting HR	68.50 (63.25, 74.25)	64.50 (58.25, 72.50)	68.00 (61.00, 71.75)	N/A	N/A	N/A	0.856 (0.01)
SBP	141.50 (120.50, 169.25)	144.50 (125.75, 155.50)	135.00 (121.50, 150.25)	N/A	N/A	N/A	0.706 (0.03)
DBP	81.50 (73.50, 89.00)	80.50 (73.75, 87.50)	84.50 (74.75, 86.75)	N/A	N/A	N/A	0.401 (0.08)
MAP	102.17 (89.17, 115.25)	102.00 (94.08, 109.83)	100.67 (91.00, 106.92)	N/A	N/A	N/A	0.779 (0.02)
FMA	80.00 (72.00, 87.75)	**87.00 (73.25, 94.50)**	**96.00 (79.00, 98.00)**	**0.025 (0.65)***	**0.001 (1.00)***	**0.011 (0.74)***	**0.001 (0.98)****

Note-* $p < 0.05$ utilized by Wilcoxon signed-rank test; ** $p < 0.05$ utilized by Friedman test; CAVI: Cardio-Ankle Vascular Index; ABI: Ankle-Brachial Index; LF: low frequency; LFnu: normalized low frequency; HF: high frequency; HFnu: normalized high frequency; LF/HF ratio: low frequency to high frequency ratio; Resting HR: Resting Heart Rate; SBP: Systolic Blood Pressure; DBP: Diastolic Blood Pressure; MAP: Mean Arterial Pressure, FMA: Fugl-Meyer Assessment; N/A: Not applicable.

4.3 Effect of Boxing Training

The outcome measurements at baseline, after 4 weeks, and after 8 weeks of training are presented in Table 2. The 8-week boxing training program resulted in significant changes in both right ($p = 0.001$) and left CAVI ($p = 0.001$). These significant changes were evident as early as the 4th week of the program. In contrast, ABI values remained stable throughout the training period. Furthermore, the 8-week boxing training program resulted in a statistically significant improvement in FMA scores ($p = 0.001$). This improvement was already evident by the 4th week of the program ($p = 0.001$). LF (nu) and the LF/HF ratio showed statistically significant increases ($p = 0.013$ and $p = 0.017$, respectively).

5. Discussion

The 8-week boxing training program resulted in reduced arterial stiffness, improved cardiovascular autonomic function, and better recovery of upper and lower limb motor impairments. The boxing training program in this study represents a moderate-intensity

aerobic exercise consistent with American Heart Association guidelines (American College of Sports Medicine, 2013). Moderate-intensity aerobic activity is particularly important for reducing arterial stiffness, as it enhances endothelial function, increases nitric oxide bioavailability, and promotes arterial compliance (Nystoriak & Bhatnagar, 2018). Additionally, the rhythmic and bilateral movements characteristic of boxing may further support vascular benefits by promoting consistent alternating limb activation, thereby improving blood circulation and reducing vascular resistance. These coordinated movements likely stimulate peripheral vasodilation and improve arterial elasticity. Overall, the combined effects of moderate aerobic intensity and coordinated rhythmic movements in boxing may contribute to improvements in arterial stiffness and cerebral blood flow (Woolley et al., 2015).

Our study showed a significant reduction in arterial stiffness, with CAVI decreasing by 3% on the left side and 6% on the right side within a 4-week training period. This duration is markedly shorter than the timelines reported in previous studies involving stroke patients that observed changes in arterial stiffness (Billinger et al., 2012; Lee et al., 2015; Takatori et al., 2012). This outcome may be attributed to the specific design of the boxing training regimen, which incorporated appropriate aerobic intensity levels, structured training protocols, and adequate rest intervals, all tailored to meet the needs of individuals with chronic stroke. Although participants were allowed rest intervals between sets (each boxing round lasting 3 minutes), the time spent warming up, stretching, and performing air punching enabled them to engage in continuous exercise for a substantial duration, typically 13–15 minutes, during the initial phase of training. Aerobic exercise for stroke patients can begin with 10-minute sessions, with gradual 5-minute increments introduced every two weeks. However, from the second week onward, all participants were able to complete at least 30 minutes of continuous boxing training. The punching positions encouraged coordinated movement of the upper limbs and torso, involving the sagittal, longitudinal, and transverse planes during the execution of jab, uppercut, and hook punches, respectively (Thomson et al., 2013). These movements involve repetitive actions in which the upper-limb muscles work together in a coordinated manner to resist the force of the punching bag. As a result, this regimen helps enhance upper-limb muscular endurance and power, benefiting both aerobic conditioning and overall muscular performance (Chaabène et al., 2015). Participants exhibited significant improvements in motor recovery of both the upper and lower limbs, as indicated by an 8.75% increase in FMA scores, with notable progress evident as early as the fourth week. An increase in strength, endurance, and power of the upper limb muscles. Such improvements may contribute to increased capillary density and the development of small arterial branches (Nystoriak & Bhatnagar, 2018), resulting in greater overall arterial diameter. The observed decrease in CAVI may be attributed to improved arterial dilatation or increased nitric oxide secretion along the arterial walls, both of which can be stimulated by aerobic exercise (Nystoriak & Bhatnagar, 2018). Furthermore, consistent aerobic exercise can reduce sympathetic adrenergic vasoconstriction, thereby increasing arterial compliance and enhancing vascular elasticity (Tanaka, 2019). However, it is important to note that this study did not directly assess nitric oxide levels or vascular elasticity.

Despite reductions in CAVI following training, no statistically significant changes were observed in peripheral arterial stenosis as evaluated by ABI. The lack of change in ABI may be attributed to the fact that most participants had ABI values within the normal range before beginning the training. It can be inferred that the intensity of the boxing training program may not have been sufficient to influence peripheral arterial stenosis in individuals without pre-existing abnormalities. Additionally, ischemic stroke patients may not always present with symptoms of PAD. However, one participant's right ABI improved from 0.89 to 1.01 at week 4 and further increased to 1.02 by week 8. This finding suggests that boxing training might have a positive effect on ABI among individuals with initially abnormal values.

HRV is an index of cardiac function and an indicator of central modulation of global stress responses (Guan et al., 2018), therefore it was chosen as the outcome measure for this study. After the boxing training program, we observed a decrease in HF value and an increase in LF value. However, the simultaneous rise in the LF/HF ratio suggests improved sympathovagal balance, indicating enhanced autonomic regulation of cardiac function as a result of the training.

This finding appears to contradict previous research reporting a decrease in LF and an increase in HF, indicative of reduced sympathetic activity and enhanced parasympathetic activity, respectively (Sampaio et al., 2016). This discrepancy may be due to the specific focus on ischemic stroke patients who

often exhibit lower HRV values than those with other stroke types (Al-Qudah et al., 2015) and healthy individuals (Korpelainen et al., 1996). The alterations in LF, HF, and LF/HF ratios are expected to move toward values observed in healthy individuals (Kelley et al., 2001), suggesting that boxing training may help normalize HRV in stroke patients. Furthermore, the moderate-to-high intensity, rhythmic structure, and bilateral full-body movements characteristic of boxing resemble those of other martial arts, which have been associated with improved cardiac autonomic modulation, although prior studies were conducted in healthy children and adolescents rather than in individuals post-stroke (Suetake et al., 2018). Although HRV is influenced primarily by heart rate (HR) (Kazmi et al., 2016), the resting HR of our participants remained largely consistent throughout the training program. However, 7 of the 12 participants demonstrated a decrease in resting heart rate following the training. The decreased heart rate and elevated LF/HF ratio observed after the boxing training may indicate increased heart rate variability, potentially reflecting improved functional status (Ogliari et al., 2015). Temporal changes in autonomic nervous system activity, as reflected in HRV, did not affect participants' stable blood pressure, which may be attributable to consistent medication adherence. Although statistically significant changes in blood pressure were not observed after the boxing training, participants demonstrated a notable trend toward decreasing blood pressure, including a 4% reduction in diastolic pressure and a 2% reduction in mean arterial pressure. These findings are consistent with prior research demonstrating the efficacy of aerobic exercise in reducing resting blood pressure among adults (Kelley et al., 2001).

In this study, FMA scores showed a notable increase that exceeded the Minimal Clinically Important Difference (MCID) for both FMA-UE and FMA-LE assessments, surpassing 4.25 and 6 points, respectively (Page et al., 2015; Pandian et al., 2016). The recovery of limb motor impairment also progressed more rapidly than in previous studies (Park et al., 2017). This enhanced motor improvement may be attributed to specific components of the boxing training protocol, particularly its high intensity, rhythmic structure, and incorporation of bilateral, multiplanar movements involving both the upper and lower limbs. Unlike previous studies that limited training to seated positions and simple sagittal-plane punches (e.g., jabs and straight punches), the present program engaged more muscle groups and promoted dynamic balance and coordination, likely contributing to superior motor outcomes.

Participant motivation and a novelty effect may have contributed to the observed outcomes. The absence of dropouts after starting the boxing program suggests strong engagement and motivation, and participants' ability to complete the entire program may also reflect a novelty effect. However, an important strength of this study is that all participants were in the chronic phase of ischemic stroke, during which spontaneous recovery is minimal (Cramer, 2008). Therefore, the physiological and functional improvements observed are likely attributable to the specific effects of the boxing training program rather than to natural recovery or non-specific factors. This study has several limitations, notably the absence of a control group. Consequently, it is difficult to definitively attribute the observed changes solely to the training program. The limited sample size and single-centre data collection further constrain the generalizability of the findings. Therefore, the results serve as preliminary evidence and highlight the need for further investigation. Future research should prioritize calculating an appropriate sample size to enhance statistical robustness. Adapting the boxing program for home-based self-practice would also allow for extended observation through long-term follow-up. This will enable the evaluation of whether subjects can sustain self-training and provide insights into the duration of training effects over time. This study did not restrict participants by sex or lesion side to enhance the generalizability of the findings to stroke survivors. However, future research may focus on a single sex or lesion side to better understand sex-specific and side-specific effects of the intervention. Another limitation is the use of short-term HRV measurements, which may not fully capture real-world HRV variability in individual patients. Future research should incorporate longer-term HRV measurements to more accurately reflect autonomic nervous system function (Shaffer et al., 2020).

6. Conclusion

This study provides preliminary evidence that an 8-week, moderate-intensity boxing program can improve arterial stiffness, autonomic function, and motor performance in individuals with chronic ischemic stroke. Clinically meaningful gains in FMA scores and early reductions in CAVI highlight both functional and vascular benefits. Although ABI remained unchanged, HRV parameters indicated improved autonomic balance. Given the small sample

size and absence of a control group, these findings should be interpreted cautiously. Larger controlled trials with long-term follow-up are needed to confirm the therapeutic value of boxing as a feasible and engaging adjunct to stroke rehabilitation.

7. Acknowledgements

We extend our sincere gratitude to Assoc. Prof. Dr. Chaiyong Jorrakate and Assoc. Prof. Dr. Orawan Keeratisiroj for their valuable guidance and support in statistical analysis. We also thank Mr. Kevin Roebl for his assistance in proofreading and refining the manuscript.

8. Abbreviations

Abbreviation	Full Term
ABI	Ankle–Brachial Index
AS	Arterial Stiffness
BP	Blood Pressure
CAVI	Cardio–Ankle Vascular Index
ECG	Electrocardiogram
FMA	Fugl–Meyer Assessment
FMA-UE	Fugl–Meyer Assessment – Upper Extremity
FMA-LE	Fugl–Meyer Assessment – Lower Extremity
HF	High Frequency
HFnu	High Frequency (Normalized Units)
HR	Heart Rate
HRV	Heart Rate Variability
IHaDS	Interdisciplinary Health and Data Sciences Research Unit
IQR	Interquartile Range
IRB	Institutional Review Board
LF	Low Frequency
LFnu	Low Frequency (Normalized Units)
LF/HF	Low Frequency to High Frequency Ratio
MAP	Mean Arterial Pressure
MCID	Minimal Clinically Important Difference
MMSE-Thai 2002	Mini-Mental State Examination (Thai Version 2002)
PAD	Peripheral Artery Disease
RPE	Rating of Perceived Exertion
Rt. / Lt.	Right / Left
SBP	Systolic Blood Pressure
DBP	Diastolic Blood Pressure
SD	Standard Deviation
SPSS	Statistical Package for the Social Sciences
TCTR	Thai Clinical Trial Registration

9. CRediT Statement:

Natchaya Chondaen: Conceptualization, Methodology, Investigation, Formal Analysis, Writing – Original Draft, Writing – Review & Editing
Olan Isariyapan: Investigation, Writing – Review & Editing
Jeerawan Kerdsawatmongkon: Investigation, Writing – Review & Editing
Kroekkiat Chinda: Validation, Resources, Writing – Review & Editing
Benjarat Sangthong: Validation, Formal Analysis, Writing – Review & Editing
Duangnapa Roongpiboonsopit: Investigation, Writing – Review & Editing
Phatiwat Chotimol: Validation, Resources, Writing – Review & Editing
Waroonnapa Srisoparb: Conceptualization, Methodology, Investigation, Validation, Formal Analysis, Investigation, Data Curation, Writing – Original Draft, Writing – Review & Editing, Visualization, Supervision, Project Administration

10. References

Al-Qudah, Z. A., Yacoub, H. A., & Souayah, N. (2015). Disorders of the autonomic nervous system after hemispheric cerebrovascular disorders: An update. *Journal of Vascular and Interventional Neurology*, *8*(4), 43–52.

Alt Murphy, M., Resteghini, C., Feys, P., & Lamers, I. (2015). An overview of systematic reviews on upper extremity outcome measures after stroke. *BMC Neurology*, *15*(1), Article 29. https://doi.org/10.1186/s12883-015-0292-6

American College of Sports Medicine. (2013). *ACSM's guidelines for exercise testing and prescription*. Philadelphia, US: Lippincott williams & wilkins.

Billinger, S. A., Arena, R., Bernhardt, J., Eng, J. J., Franklin, B. A., Johnson, C. M., ... & Tang, A. (2014). Physical activity and exercise recommendations for stroke survivors: A statement for healthcare professionals from the American Heart Association/American Stroke Association. *Stroke*, *45*(8), 2532-2553. https://doi.org/10.1161/STR.0000000000000022

Billinger, S. A., Mattlage, A. E., Ashenden, A. L., Lentz, A. A., Harter, G., & Rippee, M. A. (2012). Aerobic exercise in subacute stroke improves cardiovascular health and physical performance. *Journal of Neurologic Physical Therapy*, *36*(4), 159-165. https://doi.org/10.1097/NPT.0b013e318274d082

Chaabène, H., Tabben, M., Mkaouer, B., Franchini, E., Negra, Y., Hammami, M., ... & Hachana, Y. (2015). Amateur boxing: Physical and physiological attributes. *Sports Medicine*, *45*(3), 337-352. https://doi.org/10.1007/s40279-014-0274-7

Chen, C. F., Lin, H. F., Lin, R. T., Yang, Y. H., & Lai, C. L. (2013). Relationship between ischemic stroke location and autonomic cardiac function. *Journal of Clinical Neuroscience*, *20*(3), 406-409. https://doi.org/10.1016/j.jocn.2012.02.047

Chen, Z., Venkat, P., Seyfried, D., Chopp, M., Yan, T., & Chen, J. (2017). Brain–heart interaction: Cardiac complications after stroke. *Circulation Research*, *121*(4), 451-468. https://doi.org/10.1161/CIRCRESAHA.117.311170

Cramer, S. C. (2008). Repairing the human brain after stroke: I. Mechanisms of spontaneous recovery. *Annals of Neurology*, *63*(3), 272-287. https://doi.org/10.1002/ana.21393

Feigin, V. L., Stark, B. A., Johnson, C. O., Roth, G. A., Bisignano, C., Abady, G. G., ... & Hamidi, S. (2021). Global, regional, and national burden of stroke and its risk factors, 1990–2019: A systematic analysis for the Global Burden of Disease Study 2019. *The Lancet Neurology*, *20*(10), 795-820. https://doi.org/10.1016/S1474-4422(21)00252-0

Gladstone, D. J., Danells, C. J., & Black, S. E. (2002). The Fugl-Meyer assessment of motor recovery after stroke: A critical review of its measurement properties. *Neurorehabilitation and Neural Repair*, *16*(3), 232-240. https://doi.org/10.1177/154596802401105171

Guan, L., Collet, J. P., Mazowita, G., & Claydon, V. E. (2018). Autonomic nervous system and stress to predict secondary ischemic events after transient ischemic attack or minor stroke: Possible implications of heart rate variability. *Frontiers in Neurology*, *9*, Article 90. https://doi.org/10.3389/fneur.2018.00090

Hong, J. B., Leonards, C. O., Endres, M., Siegerink, B., & Liman, T. G. (2016). Ankle-brachial index and recurrent stroke risk: Meta-analysis. *Stroke*, *47*(2), 317-322. https://doi.org/10.1161/STROKEAHA.115.011321

Julious, S. A. (2005). Sample size of 12 per group rule of thumb for a pilot study. *Pharmaceutical Statistics: The Journal of Applied Statistics in the Pharmaceutical Industry*, *4*(4), 287-291. https://doi.org/10.1002/pst.185

Kazmi, S. Z. H., Zhang, H., Aziz, W., Monfredi, O., Abbas, S. A., Shah, S. A., ... & Butt, W. H. (2016). Inverse correlation between heart rate variability and heart rate demonstrated by linear and nonlinear analysis. *PloS One*, *11*(6), Article e0157557. https://doi.org/10.1371/journal.pone.0157557

Kelley, G. A., Kelley, K. A., & Vu Tran, Z. (2001). Aerobic exercise and resting blood pressure: A meta-analytic review of randomized, controlled trials. *Preventive Cardiology*, *4*(2), 73-80. https://doi.org/10.1111/j.1520-037X.2001.00529.x

Kerdsawatmongkon, J., Nualnetr, N., Isariyapan, O., Kitreerawutiwong, N., & Srisoparb, W. (2023). Effects of home-based boxing training on trunk performance, balance, and enjoyment of patients with chronic stroke. *Annals of Rehabilitation Medicine*, *47*(1), 36-44. https://doi.org/10.5535/arm.22127

Khan, T. H., Farooqui, F. A., & Niazi, K. (2008). Critical review of the ankle brachial index. *Current Cardiology Reviews*, *4*(2), 101-106. https://doi.org/10.2174/157340308784245810

Kleiger, R. E., Stein, P. K., & Bigger Jr, J. T. (2005). Heart rate variability: Measurement and clinical utility. *Annals of Noninvasive Electrocardiology*, *10*(1), 88-101. https://doi.org/10.1111/j.1542-474X.2005.10101.x

Korpelainen, J. T., Sotaniemi, K. A., Huikuri, H. V., & Myllylä, V. V. (1996). Abnormal heart rate variability as a manifestation of autonomic dysfunction in hemispheric brain infarction. *Stroke*, *27*(11), 2059-2063. https://doi.org/10.1161/01.STR.27.11.2059

Lee, H. S., Lee, H. L., Han, H. S., Yeo, M., Kim, J. S., Lee, S. H., ... & Shin, D. I. (2016). Clinical usefulness of ankle brachial index and brachial-ankle pulse wave velocity in patients

with ischemic stroke. *Journal of Biomedical Research*, *30*(4), 285-291. https://doi.org/10.7555/JBR.30.2016K0006

Lee, Y. H., Park, S. H., Yoon, E. S., Lee, C. D., Wee, S. O., Fernhall, B., & Jae, S. Y. (2015). Effects of combined aerobic and resistance exercise on central arterial stiffness and gait velocity in patients with chronic poststroke hemiparesis. *American Journal of Physical Medicine & Rehabilitation*, *94*(9), 687-695. https://doi.org/10.1097/PHM.0000000000000233

McClary, K. N., & Massey, P. (2025). *Ankle Brachial Index.* Florida, United States: StatPearls Publishing LLC.

Nystoriak, M. A., & Bhatnagar, A. (2018). Cardiovascular effects and benefits of exercise. *Frontiers in Cardiovascular Medicine*, *5*, Article 408204. https://doi.org/10.3389/fcvm.2018.00135

Ogliari, G., Mahinrad, S., Stott, D. J., Jukema, J. W., Mooijaart, S. P., Macfarlane, P. W., ... & Sabayan, B. (2015). Resting heart rate, heart rate variability and functional decline in old age. *Canadian Medical Association Journal*, *187*(15), E442-E449. https://doi.org/10.1503/cmaj.150462

Orini, M., van Duijvenboden, S., Young, W. J., Ramírez, J., Jones, A. R., Hughes, A. D., ... & Lambiase, P. D. (2023). Long-term association of ultra-short heart rate variability with cardiovascular events. *Scientific Reports*, *13*(1), Article 18966. https://doi.org/10.1038/s41598-023-45988-2

Page, S. J., Hade, E., & Persch, A. (2015). Psychometrics of the wrist stability and hand mobility subscales of the Fugl-Meyer assessment in moderately impaired stroke. *Physical Therapy*, *95*(1), 103-108. https://doi.org/10.2522/ptj.20130235

Pandian, S., Arya, K. N., & Kumar, D. (2016). Minimal clinically important difference of the lower-extremity fugl–meyer assessment in chronic-stroke. *Topics in Stroke Rehabilitation*, *23*(4), 233-239. https://doi.org/10.1179/1945511915Y.0000000003

Park, J., Gong, J., & Yim, J. (2017). Effects of a sitting boxing program on upper limb function, balance, gait, and quality of life in stroke patients. *NeuroRehabilitation*, *40*(1), 77-86. https://doi.org/10.3233/NRE-161392

Raimundo, R. D., Zangirolami-Raimundo, J., Leone, C., de Carvalho, T. D., da Silva, T. D., Bezerra, I. M. P., ... & de Abreu, L. C. (2021). The use of cardiac autonomic responses to aerobic exercise in elderly stroke patients: Functional rehabilitation as a public health policy. *International Journal of Environmental Research and Public Health*, *18*(21), Article 11460. https://doi.org/10.3390/ijerph182111460

Sampaio, L. M. M., Subramaniam, S., Arena, R., & Bhatt, T. (2016). Does virtual reality-based kinect dance training paradigm improve autonomic nervous system modulation in individuals with chronic stroke?. *Journal of Vascular and Interventional Neurology*, *9*(2), 21-29.

Shaffer, F., & Ginsberg, J. P. (2017). An overview of heart rate variability metrics and norms. *Frontiers in Public Health*, *5*, Article 258. https://doi.org/10.3389/fpubh.2017.00258

Shaffer, F., Meehan, Z. M., & Zerr, C. L. (2020). A critical review of ultra-short-term heart rate variability norms research. *Frontiers in Neuroscience*, *14*, Article 594880. https://doi.org/10.3389/fnins.2020.594880

Shirai, K., Hiruta, N., Song, M., Kurosu, T., Suzuki, J., Tomaru, T., ... & Takata, M. (2011). Cardio-ankle vascular index (CAVI) as a novel indicator of arterial stiffness: Theory, evidence and perspectives. *Journal of Atherosclerosis and Thrombosis*, *18*(11), 924-938. https://doi.org/10.5551/jat.7716

Shirai, K., Utino, J., Otsuka, K., & Takata, M. (2006). A novel blood pressure-independent arterial wall stiffness parameter; cardio-ankle vascular index (CAVI). *Journal of Atherosclerosis and Thrombosis*, *13*(2), 101-107. https://doi.org/10.5551/jat.13.101

Su, N., Zhai, F. F., Ni, J., Zhou, L. X., Yao, M., Peng, B., ... & Cui, L. Y. (2017). Pulse pressure within 3 months after ischemic stroke is associated with long-term stroke outcomes. *American Journal of Hypertension*, *30*(12), 1189-1195. https://doi.org/10.1093/ajh/hpx121

Suetake, V. Y., Franchini, E., Saraiva, B. T., Da Silva, A. K., Bernardo, A. F., Gomes, R. L., ... & Christofaro, D. G. (2018). Effects of 9 months of martial arts training on cardiac autonomic modulation in healthy children and adolescents. *Pediatric Exercise Science*, *30*(4), 487-494. https://doi.org/10.1123/pes.2017-0083

Sun, C. K. (2013). Cardio-ankle vascular index (CAVI) as an indicator of arterial stiffness. *Integrated Blood Pressure Control*, 27-38. https://doi.org/10.2147/IBPC.S34423

Suzuki, J., Sakakibara, R., Tomaru, T., Tateno, F., Kishi, M., Ogawa, E., ... & Shirai, K. (2013). Stroke and cardio-ankle vascular stiffness index. *Journal of Stroke and Cerebrovascular Diseases*, *22*(2), 171-175. https://doi.org/10.1016/j.jstrokecerebrovasdis.2011.07.010

Sztajzel, J. (2004). Heart rate variability: A noninvasive electrocardiographic method to measure the autonomic nervous system. *Swiss Medical Weekly*, *134*(3536), 514-522. https://doi.org/10.4414/smw.2004.10321

Takatori, K., Matsumoto, D., Okada, Y., Nakamura, J., & Shomoto, K. (2012). Effect of intensive rehabilitation on physical function and arterial function in community-dwelling chronic stroke survivors. *Topics in Stroke Rehabilitation*, *19*(5), 377-383. https://doi.org/10.1310/tsr1905-377

Tanaka, H. (2019). Antiaging effects of aerobic exercise on systemic arteries. *Hypertension*, *74*(2), 237-243. https://doi.org/10.1161/HYPERTENSIONAHA.119.13179

Thai Cognitive Test Development Committee. (2002). Mini-mental state examination-Thai 2002. *Bangkok, Thailand: Institute of Geriatric Medicine, Department of Medical Services, Ministry of Public Health*.

Thomson, E., Lamb, K., & Nicholas, C. (2013). The development of a reliable amateur boxing performance analysis template. *Journal of Sports Sciences*, *31*(5), 516-528. https://doi.org/10.1080/02640414.2012.738922

Trinh, T., Scheuer, S. E., Thompson-Butel, A. G., Shiner, C. T., & McNulty, P. A. (2016). Cardiovascular fitness is improved post-stroke with upper-limb Wii-based Movement Therapy but not dose-matched constraint therapy. *Topics in Stroke Rehabilitation*, *23*(3), 208-216. https://doi.org/10.1080/10749357.2016.1138672

Woolley, B., Stoner, L., Lark, S., Wong, L., Lanford, J., & Faulkner, J. (2015). Effect of early exercise engagement on arterial stiffness in patients diagnosed with a transient ischaemic attack. *Journal of Human Hypertension*, *29*(2), 87-91. https://doi.org/10.1038/jhh.2014.56

Zhang, D., Lu, Y., Zhao, X., Zhang, Q., & Li, L. (2020). Aerobic exercise attenuates neurodegeneration and promotes functional recovery–Why it matters for neurorehabilitation & neural repair. *Neurochemistry International*, *141*, Article 104862. https://doi.org/10.1016/j.neuint.2020.104862

Zhang, H., Xie, Q., & Hu, J. (2022). Neuroprotective effect of physical activity in ischemic stroke: Focus on the neurovascular unit. *Frontiers in Cellular Neuroscience*, *16*, Article 860573. https://doi.org/10.3389/fncel.2022.860573