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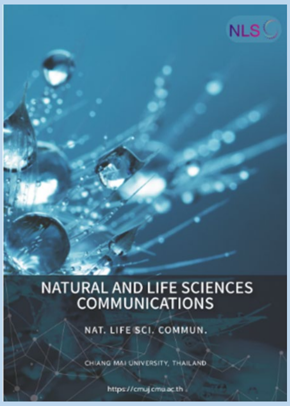

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Corresponding author:
Sainatee Pratanaphon,
E-mail: sainatee.pra@cmu.ac.th

Jump Roping High-Intensity Interval Training Enhances Vascular Function in Adults with Overweight/Obesity

Orathai Intawong[1], Kanpiraya Nithitsutthibuta[2], Jaruta Kunritt[2], and Sainatee Pratanaphon[2,*]

1 Sport Science Programme, Chiang Mai University, Chiang Mai 50200, Thailand.
2 Department of Physical Therapy, Faculty of Associated Medical Science, Chiang Mai University, Chiang Mai 50200, Thailand.

ABSTRACT

A few studies have shown that body-weight- and laboratory-based high-intensity interval training (HIIT) effectively improves endothelial function. However, the effect of HIIT in the form of jump roping that significantly increases vertical ground reaction force on endothelial function remains unknown. Thus, the objective of this study was to determine the effects of a 12-week jump roping exercise programme on vascular function in adults with overweight/obesity. Twenty young adults with overweight/obesity were randomly assigned to the exercise or control group. The exercise group performed 12 intervals jump roping HIIT – 1 minute at 85%–95% maximal heart rate (HRmax) and 1 minute at 50%–70% HRmax – for 12 weeks (five sessions per week). The control group was asked to maintain the usual lifestyle pattern throughout the study period. The outcome measures were per cent flow-mediated dilation (%FMD), baseline artery diameter (FMDbase), peak artery diameter (FMDpeak), mean blood flow velocity (MBFV) and per cent body fat (%BF). Results revealed that there was a significant group × time interaction for %FMD, FMDpeak and MBFV after the intervention (all *P* <0.05). There was no significant group × time interaction for the other variables. There were no significant changes in the outcome variables between pre- and post-intervention and between the groups (all *P* >0.05), except for %FMD. In conclusion, jump roping HIIT increased %FMD, FMDpeak and MBFV, indicating the cardiovascular-protective effects of this approach in adults with overweight/obesity.

Keywords: Vascular function, High-intensity interval training, Jump roping, Overweight, Obesity

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INTRODUCTION

Vascular function is the ability of endothelial and smooth muscle cells to respond to a stimulant or shear stress stimulus inducing nitric oxide (NO) production to modulate vascular tone and blood flow (Corretti et al., 2002). It is well known that people with overweight/obesity have endothelial dysfunction (ED), assessed by flow-mediated dilation (FMD), due to reduce NO availability. Therefore, obesity-induced ED is considered a major risk factor for developing cardiovascular disease (CVD) and increased subclinical atherosclerosis (Mengozzi et al., 2020; Li et al., 2021). Consistently, a systematic review and meta-analysis reported that overweight/obesity is associated with lower FMD and greater carotid intima-media thickness (Ne et al., 2017). Therefore, there should be a focus on an intervention-induced improvement in vascular function to tackle obesity.

A growing body of evidence has demonstrated that high-intensity interval training (HIIT) – which involves brief intervals of intense exercise interspersed with periods of low-intensity exercise or rest – enhances vascular endothelial function better than moderate-intensity continuous training (MICT) (Ramos et al., 2015; Cassidy et al., 2017; Khalafi et al., 2022). HIIT also tends to improve other indicators of cardiometabolic health including cardiorespiratory fitness (CRF), oxidative stress, inflammation, insulin sensitivity and CVD risk factors. Four intervals of 4 minutes (4 × 4 HIIT), three times per week for at least 12 weeks has been recommended to enhance vascular function (Ramos et al., 2015). However, there are practical limitations in sedentary individuals with obesity: the intensity of the exercise and common barriers including the inconvenience of exercise and the unavailability of facilities (Hardcastle et al., 2014; Biddle and Batterham, 2015). Interestingly, two studies reported the positive effects of 12-week low-volume HIIT at ≥ 80% maximal heart rate (HRmax) interspersed with active recovery or rest on both brachial FMD and aortic stiffness in individuals with obesity and on FMD in patients with type 2 diabetes mellitus (Afousi et al., 2018; Scott et al., 2019). However, these studies used body-weight- and laboratory-based HIIT (i.e. a cycle ergometer) as the exercise mode.

Jump roping is an exercise of considerable interest because it has the properties of a plyometric exercise involving the arms, legs and torso movements with a relatively low risk of injury (Kim et al., 2017). It requires metabolic equivalent (MET) values of 11.7-12.5, which means it is defined as a high-intensity cardiorespiratory exercise (Town et al., 1980). It also elicits more enjoyment than MICT, utilises inexpensive equipment and requires less space (Li et al., 2022). Most studies incorporated traditional jump roping training for improving physical fitness in athletes (Ozer et al., 2011; Makaruk, 2013; Trecroci et al., 2015; García-Pinillos et al., 2020). Twelve weeks of jump roping using low-to-moderate-intensity continuous training led to significant improvements in blood pressure, arterial stiffness, NO bioavailability, systemic inflammation and per cent body fat (%BF) in adolescent girls with prehypertension (Sung et al., 2019). However, little is known about the effect of jump roping HIIT on endothelial function. We hypothesise that the mechanical effect of jump roping – which increases vertical ground reaction force (VGRF) by 2.5-4 times the body weight when performed at 72–132 skips/minute (Yamaguchi et al., 2000) – ameliorates ED in adults with overweight/obesity.

MATERIAL AND METHODS

Study design

A two-arm parallel design was conducted. The participants were randomly assigned to one of two groups: the exercise group (n=10) and the control group (n=10). Outcome measures carried out at the same time of the day, on two occasions; at baseline and 12 weeks after the intervention. All assessment was done at the same time of day. All participants were asked to maintain their routine lifestyle and dietary habits throughout the study. The caloric intake was recorded pre- and post-intervention.

Participants

Twenty young adults with overweight/obesity were recruited through the university's social media and in person. The inclusion criteria were age between 18 and 40 years, a body mass index (BMI) of 23.0-27.5 kg/m^2 according to the World Health Organization criteria (WHO Expert Consultation, 2004) and a sedentary lifestyle (did not participate in sport or moderate physical activity [less than 30 minutes per day, three times per week] (Reljic et al., 2018). The exclusion criteria were illnesses that affected the outcome measures such as cardiopulmonary disease, diabetes mellitus, hypertension, thyroidism, musculoskeletal injury of the upper and lower extremities and receiving any other interventions (e.g. participation in a weight control programme or other exercise programme). Written informed consent was obtained for all participants. The study procedures were carried out in accordance with the ethical standards of the institutional research committee (AMSEC-65FB-005) and complied with the Declaration of Helsinki.

Sample size calculation

There is no evidence for the effects of jump roping HIIT on endothelial function in individuals with obesity. The sample size was calculated using G*Power 3.1.9.4, based on a previous study that showed a significant increase in FMD (pre-HIIT = 5.23±2.80%, post-HIIT = 8.98±2.86%) after 8 weeks of low-volume HIIT using cycle ergometer in obese adults (Sawyer et al., 2016). Thus, the total sample size was 20 (80% power and alpha of 0.05).

Exercise protocols

A training session consisted of a 5-minute warm-up, jump roping HIIT with a speed that increased heart rate to reach 85%-95% HRmax for 60 seconds, alternating with active recovery to keep the heart rate at 50%-70% HRmax for 60 seconds, and a 5-minute cool-down. Twelve sets of jump roping HIIT with the jumping height set at 0.5 inches, lasting for a total of 24 minutes, were completed each day, five times a week for 12 weeks. There were four jump roping exercises, namely standard jumps, jump roping heel toe step, alternate-foot jump and jump roping side swing; there were three repetitions per pose. Heart rate and the exercise intensity were monitored during exercise using a heart rate monitor (Polar Oy, Kempele, Finland) and Borg's rating of perceived exertion scale (RPE, from 0 to 10), respectively. HRmax was determined based on the equation reported by Tanaka et al (2001). The participants were familiarised with the exercise protocol via 5 days of jump roping training as described by García-Pinillos et al. (2020). All exercise sessions were supervised by a physical educator. The control group did not participate in the exercise or activities during the study period.

Outcome variables

Anthropometry

Height was measured to the nearest 0.2 cm with a stadiometer. Body composition was analysed with a bioelectrical impedance analyser (Tanita BC-418, Tokyo, Japan), which recorded total body mass, %BF and fat-free mass.

Vascular function

FMD was assessed using colour Doppler ultrasound in the pulsed wave Doppler mode (Aplio 400, Toshiba, the Netherlands) based on published guidelines (Corretti et al., 2002; Thijssen et al., 2011; Harris et al., 2010; Rodriguez-Miguelez et al., 2016). The participants were instructed to lay supine with their right arm extended to 80°-90° at heart level in a quiet, temperature-controlled room at 25°C. An occlusion cuff was placed around the right forearm distal to the probe with the proximal border adjacent to the medial epicondyle. After resting for 15 minutes, a probe with an insonation angle of 60° was placed to image the brachial artery in the distal third of the upper arm. The occlusion cuff was inflated to 200 mmHg for 5 minutes, then deflated and the brachial artery was tracked every 30 seconds for a total of 2 minutes to determine the peak arterial diameter (FMDpeak). The basal artery diameter (FMDbase) was measured during the resting stage before the intervention. The per cent change in FMD (%FMD) was calculated by using a formula: [(FMDpeak – FMDbase)/(FMDbase)] × 100. The mean blood flow velocity at baseline (MBFVbase) and after the release of cuff occlusion (MBFVpost) were determined. Prior to the FMD assessments, the participants were asked to fast for at least 8-12 hours; to abstain from strenuous exercise, caffeine and alcohol consumption for at least 8 hours; and to avoid eating or drinking for 4 hours. The intra-rater and inter-rater reliability of the FMD measurement was within an acceptable range (intraclass correlation coefficient (ICCS) = 0.92, and 0.87, all P <0.001, repectively). The standard error of the measurement (SEM) and the smallest detectable change for %FMD were 0.92 and 2.54, respectively.

Statistical analysis

The Shapiro-Wilk test was conducted to determine whether the data met the normality assumption. All data sets had a normal distribution. An independent t-test was used to compare the differences in baseline characteristics between the two groups. A mixed model analysis of covariance (ANCOVA) was performed, with age and BMI, the strongest independent predictors of FMD (Heiss et al., 2023), used as covariates to determine the interaction between the two independent variables, namely training (pre- and post-intervention) and group (exercise and control) on FMDbase, FMDpeak, %FMD, MBFV and %BF. When there was a significant main effect or interaction, paired t-tests were used for post hoc comparisons. Partial eta squared (η^2) was used to measure the effect size of outcome variables for ANCOVA. The thresholds for small, moderate and large effects were defined as 0.01, 0.06 and 0.14, respectively (Richardson, 2011). All data were analysed using SPSS Statistics version 21.0 (IBM Corp., Armonk, NY, USA) with statistical significance at P <0.05.

RESULT

Participant characteristics

A total of 20 adults with overweight/obesity participated in the study. They were randomly assigned to the exercise group (seven women and one man) and the control group (nine women and one man). During training, two participants in the exercise group withdrew after 6 weeks of exercise due to lack of time and a busy schedule. The compliance rate with the jump roping exercise was 80% (48/60 times). There were no adverse effects over the course of training. There was leg muscle tenderness in a few participants during the early phase of training; it resolved within a few days. As shown in Table 1, there were no significant differences in the variables at baseline between the groups (all *P* >0.05). There was no group difference over time and between groups in mean daily caloric intake (*P* >0.05).

Table 1. Characteristics of participants.

Variables	Jump rope group (n=8)	Control group (n=10)	*P*-value
Age (years)	28.88 ± 4.42	30.40 ± 2.84	0.38
Sex (male: female)	1: 7	1: 9	
Height (meter)	1.60 ± 0.57	1.64 ± 0.07	0.14
Body weight (kilogram)	61.13 ± 5.56	67.29 ± 8.49	0.15
Body mass index (kg/m^2)	24.41 ± 1.69	24.90 ± 1.52	0.53
Percent body fat (%)	34.01 ± 4.71	34.88 ± 4.62	0.70
Systolic blood pressure (mmHg)	118.88 ± 9.95	114.20 ± 9.07	0.31
Diastolic blood pressure (mmHg)	83.25 ± 11.08	74.70 ± 5.10	0.07
Resting heart rate (bpm)	78.75 ± 13.27	74.70 ± 5.10	0.33
Daily caloric intake (kcal/day)			
- pre intervention	1,184.58 ± 180.23	1,182.90 ± 256.12	0.98
- post intervention	1,175.08 ± 198.57	1,142.27 ± 286.14	0.78

Note: Represented as mean (standard deviation) Abbreviation; kg = kilogram, m = meter, m^2 = square meter, bpm = beats per minute, kcal = kilocalory, mmHg = millimeters of mercury

Effects of high-intensity interval training on vascular function and %BF

As shown in Table 2, the mixed-model ANCOVA revealed that there was a significant interaction between the within-subject factor and group for %FMD (F=7.959, p=0.014, η^2=0.36), FMDpeak (F=7.773, *P*=0.015, η^2=0.36) and MBFV (F=13.854, *P*=0.002, η^2=0.50), but not for FMDbase (F=0.251, *P*=0.624, η^2=0.02) and %BF (F=0.937, *P*=0.349, η^2=0.06). The within-subject main effect was not significant for %FMD (F=2.576, *P*=0.131, η^2=0.16), FMDbase (F=0.214, *P*=0.651, η^2=0.02), FMDpeak (F=3.022, *P*=0.104, η^2=0.18) and %BF (F=0.324, *P*=0.578, η^2=0.02), but it was significant for MBFV (F=13.206, *P*=0.003, η^2=0.49). A paired t-test revealed no significant change in MBFV between the pre- and post-intervention in the exercise group (*P*=0.491) or the control group (*P*=0.071).

The group main effect was not significant for FMDbase (F=0.984, *P*=0.338, η^2=0.07) FMDpeak (F=0.050, *P*=0.827, η^2=0.00), MBFV (F=0.835, *P*=0.376, η^2=0.06) and %BF (F=0.000, *P*=0.990, η^2=0.00), but it was significant for %FMD (F=15.156, *P*=0.002, η^2=0.52). An independent t-test indicated that the exercise group had a significantly greater change in %FMD than the control group (*P*=0.031).

Table 2. Vascular function and percent body fat after controlling for age and body mass index at pre- and post-intervention.

Variables	Jump rope group		Control group		ANCOVA (F value)		
	Pre	Post	Pre	Post	Group	Time	Interaction
Flow-mediated dilation (%)	12.17 ± 1.18	15.03 ± 1.06	11.22 ± 1.04	9.30 ± 0.94	15.15*	2.57	7.95†
Baseline artery diameter (mm)	3.06 ± 0.12	3.24 ± 0.16	3.33 ± 0.11	3.45 ± 0.14	0.98	0.21	0.25
Peak artery diameter (mm)	3.43 ± 0.15	3.72 ± 0.17	3.70 ± 0.13	3.77 ± 0.15	0.05	3.02	7.77†
Mean blood flow velocity (cm/s)	10.40 ± 1.20	12.55 ± 1.59	14.50 ± 1.06	10.53 ± 1.41	0.83	13.20*	13.85†
Percent body fat (%)	34.91 ± 1.64	34.67 ± 1.63	34.16 ± 1.45	34.64 ± 1.45	0.00	0.32	0.93

Note: * significantly different from before intervention, † significant interaction between time and group

DISCUSSION

The main findings in this study are that 12-week jump roping HIIT led to a significant increase in %FMD, FMDpeak and MBFV, but did not change FMDbase and %BF in adults with overweight/obesity. Additionally, there were no differences in the outcome variables between the pre- and post-intervention and between the groups (all P >0.05), except for %FMD. The exercise group showed superior improvement in %FMD compared with the control group. These results suggest that jump roping HIIT can improve vascular function thereby improving endothelial function and blood flow in adults with overweight or obesity.

A systematic review and meta-analysis showed that obesity is associated with functional and structural changes to the arterial vasculature; these changes decrease brachial FMD and increase carotid-intima thickness and subclinical atherosclerosis (Ne et al., 2017). In this study, the baseline values of arterial diameter at pre- and post-occlusion of adults with obesity were relatively low and in range with those of healthy adults in previous studies (Ostrem et al., 2015; Meríc et al., 2022). Similarly, the basal %FMD values were apparently high, but within the range of the FMD reference index (Tomiyama et al., 2015; Heiss et al., 2023). The differences in sample demographic data and FMD measurements, which may be the results of different instruments used and the reproducibility of the measurements (Tomiyama et al., 2015), were responsible for these disparities. It seems likely that the endothelial function of our participants were within normal limits.

After completing the 12-week jump roping HIIT protocol, the %FMD – which is the earliest vascular function change – had increased to a similar extent as two different exercise modes and HIIT protocols. Scott et al. (2019) found that 12 weeks of repeated 1-minute bouts of HIIT using either body weight exercises or a cycle ergometer interspersed with 1 minute of rest at ≥ 80% predicted HRmax improved %FMD, aortic stiffness and muscle capillarisation in individuals with obesity. Afousi et al. (2018) showed the positive effects on brachial artery FMD in patients with type 2 diabetes mellitus after completing repeated a 1.5-minute bout of low-volume HIIT using a cycle ergometer at 85%-90% HRmax separated by 2 minutes of active recovery at 55%-60% HRmax for 12 weeks. Also, there were no adverse effects during HIIT. Interestingly, %FMD increased by approximately 2.86% after HIIT in the present study, a change greater than the observed SEM; this change may be clinically significant because an increase in %FMD of 1% has been shown to reduce the risk of CVD (Matsuzawa et al., 2015). In addition, the observed increases in FMDpeak and blood flow in response to jump roping HIIT are consistent with a previous study (Gurovich and Braith, 2012). Those authors demonstrated that blood-flow-induced endothelial shear stress increased with exercise intensity in a dose-dependent manner in the femoral and brachial arteries. Taken together, it is plausible to conclude that 12 weeks of jump roping HIIT may reduce the risk of CVD.

We propose the following mechanisms to explain HIIT-induced the improvements in vascular function. First, the direct mechanical effects of jump roping increase VGRF, and HIIT may increase endothelial shear stress and blood flow fluctuations (Gurovich and Braith, 2012; Afousi et al., 2018), which in turn augments endothelium-dependent vasodilation through increased NO production. Vice versa, a HIIT-induced increase in blood flow provokes greater shear-stress-induced NO bioavailability and subsequently increases the arterial diameter (Wisløff et al., 2007; Tjonna et al., 2008; Molmen-Hansen et al., 2012; Cassidy et al., 2017). Second, shear stress induced by HIIT is a hyperpolarising stimulus that modifies the activity of ion channels for calcium, potassium and chloride in the vasculature and in turn causes vascular relaxation of smooth muscle cells (Gurovic and Braith, 2012). Lastly, enhanced FMD could be explained in part by a decrease in oxidative stress and subsequent increased NO bioavailability following HIIT (Wisløff et al., 2007; Tjonna et al., 2008; Mitranun et al., 2014). Further studies are warranted

Limitations of the study

This study has some strengths that should be mentioned. Specifically, a jump rope is an easily accessible instrument that can be incorporated into HIIT. Moreover, the exercise group had an 80% adherence rate and showed beneficial effects on endothelial function. There are several limitations that should be addressed. First, this study did not include healthy adults as a control group. As a result, the internal validity of the study may be affected. Second, different jump rope poses used in this study, which have different physiological demands and VGRF, may have affected the outcomes. Donnelly et al. (2013) reported that different exercises at equal intensities cause different physiological demands. Consistently, studies have shown that the alternating jump showed significant differences in VGRF, kinematic data and muscle group force of lower limbs relative to the bounced jump (Pittenger et al., 2003; Lin et al., 2022). Moreover, excessive VGRF is a concern as it can lead to knee injury. Therefore, individuals with knee problems should avoid this exercise. Lastly, the small sample size may limit the generalisability of the findings. Additional studies should involve larger samples.

CONCLUSION

The 12-week jump roping HIIT improve vascular function, resulting in enhanced %FMD increased vascular diameter, and greater blood flow velocity. These findings indicate that jump roping HIIT can be a beneficial exercise modality to improve vascular health in adults with overweight/obesity.

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AUTHOR CONTRIBUTIONS

Orathai Intawong and Sainatee Pratanaphon conceived the study, gather data for analysis and interpretation, drafted manuscript. Orathai Intawong conducted the exercise intervention. Kanpiraya Nithitsuttibutawa and Jaruta Kunritt performed anthropometric and vascular measurements. All authors have read and approved of the final manuscript.

CONFLICT OF INTEREST

The authors declare that they hold no competing interests.

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