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Original Article

The acute effects on endothelial function in the different abdominal training postures

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Abstract

To determine the acute effects of the different abdominal exercise training postures on endothelial function (flow-mediated dilatation, FMD), shear rate, blood flow, vascular resistance, heart rate and arterial blood pressure, 48 healthy untrained (inactive) male participants were randomly allocated equally to the crunch training (CR), side crunch training (SC), and leg raise training (LR) groups. All exercise training programs were designed to yield the same period of exercise session which included 16 repetitions per set for 3 sets. The CR group showed increased FMD, shear rate, blood flow, heart rate, systolic and mean arterial blood pressures (all $P<0.05$). The SC group had significantly increased shear rate, heart rate, systolic and mean arterial blood pressures, but not increase in FMD. The LR group showed significantly increased shear rate, blood flow, systolic and diastolic and mean arterial blood pressures. However, the FMD in LR group was decreased ($P<0.05$). Vascular resistance increased significantly only in LR group. In conclusion, the improved FMD was observed only in the CR group, no change in the SC group, and impaired in the LR group. Crunch training program of abdominal exercise appears to confer a significant improvement in endothelial function in inactive individuals.

Keywords: endothelial function, flow-mediated dilatation, crunch training, side crunch training, leg raise training

1. Introduction

There are many procedures for evaluating endothelial function and one of these is endothelial-dependent flow-mediated dilatation (FMD), a noninvasive index of endothelium-dependent vasodilatation (Betik *et al.*, 2004; Mitranun *et al.*, 2014). It represents the ability of vascular dilatation through the augmentation of vasodilators, shear stress or other stimuli that forms a nitric oxide (NO) dependent response (Betik *et al.*, 2004). To measure FMD, the changes of arterial diameter, mostly the brachial artery diameter was monitored by high-resolution external vascular ultrasound in response to an increase in blood flow causing shear-stress during reactive hyperemia (sphygmomanometer cuff inflation and then deflation). Endothelial dysfunction can be defined as an imbalance between vasodilating and vasoconstricting substances produced by or acting on the endothelial cells. Endothelial dysfunction is an early event of the atherosclerotic process and it is directly link to a low magnitude of FMD (Betik *et al.*, 2004; Verma *et al.*, 2003). Clinically, FMD can be used as indicator of cardiovascular disease and congestive heart failure (Brunner *et al.*, 2005).

Exercise training, a non-pharmacological therapeutic option, has shown to improve endothelial function (Tjonna *et al.*, 2008; Wisloff *et al.*, 2007). Regular participating in aerobic exercise training elicited a numbers of improvements of vascular function in healthy persons and cardiovascular disease patients (Wisløff *et al.*, 2007). A recent study of continuous and interval aerobic training in type 2 diabetic patients showed the improvement of endothelial function in both macro- and microcirculations (Mitranun *et al.*, 2014). The similar result was also achieved by resistance exercise training in patients with congestive heart failure (Maiorana *et al.*, 2000). Conversely, some cross-sectional studies have

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shown that resistance exercise training can cause arterial stiffness in young and middle-aged subjects as compared to sedentary control subjects (Bertovic *et al.*, 1999; Miyachi *et al.*, 2003).

Most of the previous studies on the prolonged exercise training showed the enhancement of FMD (Tjonna *et al.*, 2008; Wisloff *et al.*, 2007). However, single bout training is still in controversy. A previous report of handgrip training induced a decrement of FMD (Gonzales *et al.*, 2010). A single bout of resistance exercise training was also showed the impairment in FMD (Jurva *et al.*, 2006). On the contrary, an hour of aerobic exercise at 60% of maximum oxygen consumption significantly enhanced FMD in post-menopause subjects (Harvey *et al.*, 2005). Thus, the type and pattern of exercise training might be an important factor affecting acute vasculature response.

Abdominal muscles weakness can cause low back pain (Walker, 2000). Abdominal resistance exercise training is recommended for the improvement of trunk muscle strength (D'Amico *et al.*, 2007). Some abdominal training postures result in an acute hypertension due to the Valsalva effect (Finnoff *et al.*, 2003). A recent study has shown an association between FMD and exercise blood pressure in healthy adolescents through regulating blood pressure responses during submaximal exercise intensity (Lambiase *et al.*, 2014). Appropriate training postures are the most important to minimize the increments of vasoconstriction and arterial stiffness. The purpose of this study was to determine an acute effect of different abdominal training postures on FMD and blood pressure.

2. Material and Methods

2.1 Participants

The participants consisted of untrained and nonsmoking males who were 18-22 years of age. They were recruited from Srinakharinwirot University, Nakhon Nayok, Thailand. The inclusion criteria included healthy males, a baseline body mass index (BMI) value of 18.5 to 24.9 kg/sq. m, waist circumference of lower than 102 cm and no previous exercise training in the past 6 months. All participants were free from any recent injuries, and cardiovascular and cerebrovascular diseases. The present study was approved by the Ethics Committee of Srinakharinwirot University, Thailand, and conducted according to the Helsinki Declaration. An informed consent was obtained from all participants.

There were 48 male participants in this study. The eligible participants were randomly allocated in equal numbers into 3 groups: crunch training (CR), side crunch training (SC) and leg raise training (LR).

2.2 Exercise training programs

All training group (CR, SC, LR) participants underwent abdominal training program for 3 sets and having one minute for resting between each set.

Participants in the CR group started with a supine position on the mat. Both knees were flexed at 90 degree and both soles of foot were placed on the mat. Both arms were arranged in the position of crossing over the chest. Then participants practised by intense expiration. Immediately after this, the trunk was bent until the inferior angle of the scapula raised above the mat (1second from the starting position), tightening and holding for one second, then inspiring and returning to the starting position. All participants performed 16 repetitions a set for 3 sets and were allowed to have a resting period for 1 minute between each set (Figure 1).

Participants in the SC group started with a supine position similar to CR group. Then participants practised by making expiration with lifting and rotating the trunk to the left until the inferior angle of the scapula raised above the mat and the right elbow pointed to the left thigh (1 second from starting the position), tightening and holding for one second, then inspiring and returning to the starting position. After this, participants were requested to repeat this procedure by changing the rotation to the right side. All participants performed for 16 repetitions a set, alternating left and right sides, for 3 sets and were allowed to have a resting period for 1 minute between each set (Figure 2).

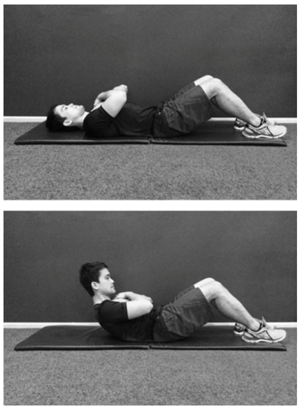

Figure 1. Crunch training.

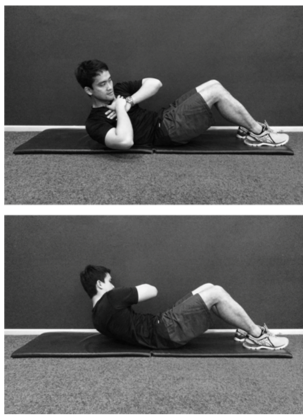

Figure 2. Side crunch training.

Participants in LR group started with a supine position on the mat with both knees in the slightly flex position. Then they practised by making expiration with lifting both legs up (hip flexion about 90 degrees) with stretched knees (1 second from the starting position), tightening and holding for one second then inspiring and returning to the starting position. All participants performed for 16 repetitions per set for 3 sets and were allowed to have the resting period for 1 minute between each set (Figure 3).

2.3 Measurements

Two hours after having breakfast, all participants were asked to measure the biological data, flow-mediated dilatation data and blood pressure data. All the post-measurements were repeated immediately after the completion of training.

2.4 Biological measures

Body fat was performed using a body composition analyzer (Omron BF511, Omron Healthcare Europe B.V., Hoofddorp, Netherlands). The participants were put in the supine position for at least 5 minutes as a resting period prior to the measurement. The blood pressure and heart rate were measured with digital blood pressure (Omron M2, Omron Healthcare Europe B.V., Hoofddorp, Netherlands) at baseline and immediately after the 3rd set of training. The mean arterial pressure (MAP) was calculated using the formula MAP = 1/3 x [systolic blood pressure – diastolic blood pressure] + diastolic blood pressure. Abdominal strength measurement was performed with weight machines (Abdominal Crunch ST-162, Johnson Health Technologies), using one repetition method (1RM).

2.5 Flow-mediated dilatation measures (FMD)

FMD was evaluated with the ultrasound equipment (SonoAce X6, Samsung Medison, Korea), using the brachial artery occlusion on the right forearm. All participants were asked to rest in the supine position for 20 min and blood pressure cuff was placed around the right forearm throughout the measurement. The brachial artery characteristics were recorded longitudinally to antecubital fossa at 1 min baseline, 5 min occlusion and 3 min deflation (Corretti *et al.*, 2002; Dhindsa *et al.*, 2008). At the occlusion period, the cuff was inflated to 50 mmHg above systolic blood pressure (Mitranun *et al.*, 2014). In order to minimize the investigator bias in image analyses, computer-based analysis program (Brachial Analyzer, Medical Imaging Applications, Coralville, IA, USA) was used for analyzing changes on vascular diameter. Shear stress presented as shear rate was calculated by blood velocity/vascular diameter (Pyke *et al.*, 2008). FMD was calculated using the equation FMD = (d2-d1) x 100/d1 when d1 is the average brachial artery diameter at baseline, d2 is the average brachial artery diameter post occlusion (Naidu *et al.*, 2011). Brachial vascular conductance was calculated as brachial blood flow/mean arterial pressure. The brachial vascular resistance is a reverse ratio of brachial vascular conductance.

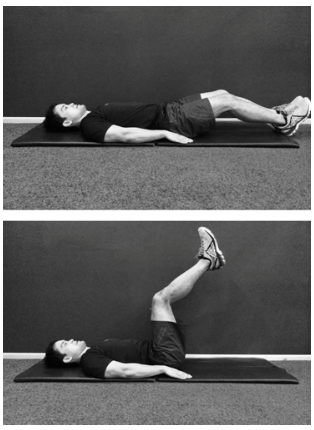

Figure 3. Leg raise training.

2.6 Statistic methods

The results were expressed as mean ± standard deviation. All the data were first checked with tests of normality. Two-way (group × time) analysis of variance with repeated measures, followed by Tukey's multiple comparison, was used to determine the significant differences among groups. A level of $P<0.05$ was considered to be a significant difference.

3. Results

Table 1 showed the baseline data of participants characteristics. Three groups; CR, SC and LR were similar in number, age, body mass, body mass index, body fat, abdominal strength, heart rate at rest, systolic blood pressure, diastolic blood pressure and mean arterial pressure.

As shown in Table 2, the brachial characteristics and blood pressure data, significant increases in FMD, shear rate, blood flow, systolic blood pressure, mean arterial pressure and heart rate were observed in the post-training of CR group as compared to the pre-training ($P<0.05$). The SC group had significantly increased shear rate, systolic blood pressure, mean arterial pressure and heart rate. The LR group showed significant increased blood flow, shear rate, systolic blood pressure, diastolic blood pressure, mean arterial pressure and heart rate. The LR group showed a significantly decrease in FMD, and the mean arterial pressure of the LR group was significantly higher than the other two groups. The significant increases in vascular resistance and decrease in vascular conductance were observed only in the LR group. There were no significant changes in baseline and peak brachial diameters in all groups.

The changes in percent of FMD in each group are shown in Figure 4. There was a significant increase in CR group and significant decrease in LR group. The lowest FMD was observed in the post-training of the LR group.

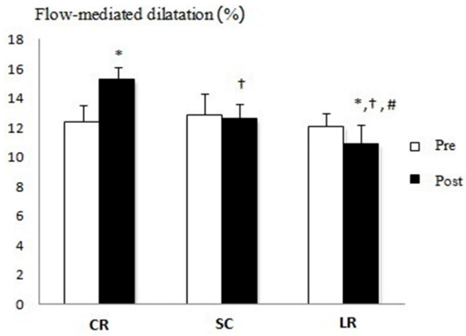

Figure 4. Flow-mediated dilatation.
CR = Crunch training group; SC = Side crunch training group; LR = Leg raise training group.
* P<0.05 vs. Pre; † P<0.05 vs. CR; # P<0.05 vs. SC.

4. Discussion

Abdominal training is an effective strategy for the improvement of core muscle strength (rectus abdominis, external oblique, rectus femoris, serratus anterior) and to prevent the symptom of back pain. Three abdominal training programs in this study concentrated on the different parts of abdominal muscle. The prime mover muscles of crunch training are the upper part of abdominal muscles, of side crunch training are the muscles in the side part of the trunk, of leg raise training are the lower part of the abdominal muscles. These different postures may affect changes in blood pressure and vascular tone by various mechanisms. In our study, we found that all of the training groups: crunch training (CR), side crunch training (SC) and leg raise training (LR),

Table 1. Baseline data of participants characteristics

	CR	SC	LR
Number (n)	16	16	16
Age (y)	20.9±0.4	19.7±0.7	19.4±0.4
Body mass (kg)	71.2±1.2	70.8±0.6	71.4±1.0
Height (cm)	172.4±0.7	171.8±1.2	171.5±0.9
Body mass index (kg/m^2)	23.5±1.0	23.9±0.9	23.6±1.2
Body fat (%)	19.0±1.5	18.8±1.3	19.2±1.4
Heart rate at rest (beat/min)	73.6±2.5	73.8±2.1	74.2±2.6
Systolic blood pressure (mmHg)	119.2±4.5	122.5±3.7	121.8±4.6
Diastolic blood pressure (mmHg)	81.5±2.7	80.9±2.0	79.6±2.5
Mean arterial pressure (mmHg)	94.3±2.4	94.6±2.1	93.7±2.1
Abdominal strength (kg)	33.5±2.4	32.3±1.8	33.9±1.5

Data are means±SD.
CR = Crunch training group; SC = Side crunch training group; LR = Leg raise training group.

Table 2. Brachial characteristics and blood pressure data

	CR		SC		LR	
	Pre	Post	Pre	Post	Pre	Post
Baseline brachial diameter (mm)	4.62±0.61	4.62±0.61	4.59±0.88	4.59±0.61	4.65±0.74	4.65±0.74
Peak brachial diameter (mm)	5.16±0.53	5.31±0.64	5.20±0.56	5.19±0.41	5.19±0.71	5.14±0.55
Flow-mediate dilatation (%)	12.4±1.1	15.3±0.8*	12.9±1.4	12.6±1.0†	12.1±0.9	10.88±1.3*†#
Shear rate (s^{-1})	38.8±1.8	41.8±1.9*	37.6±1.5	42.6±1.2*	38.3±1.7	42.5±1.3*
Blood flow (ml/min^{-1})	226.4±5.7	245.7±4.8*	234.8±4.0	247.3±5.8*	230.7±4.4	241.8±5.6*
Systolic blood pressure (mmHg)	119.2±4.5	128.6±3.3*	122.5±3.7	129.2±3.8*	121.8±4.6	130.7±5.6*
Diastolic blood pressure (mmHg)	81.5±2.7	83.1±2.0	80.9±2.0	84.2±2.6	79.6±2.5	86.6±3.1*
Mean arterial pressure	93.4±1.6	96.8±1.3*	94.1±1.1	97.1±1.0*	93.7±1.8	102.1±2.2*†#
Vascular resistance (AU)	0.39±0.03	0.40±0.02	0.40±0.01	0.40±0.01	0.39±0.01	0.43±0.01*
Vascular conductance (AU)	2.50±0.16	2.49±0.21	2.51±0.11	2.52±0.08	2.47±0.18	2.31±0.13*
Heart rate (beat/min)	73.6±2.5	107.4±3.3*	73.8±2.1	109.0±3.8*	74.2±2.6	110.2±3.6*

Data are means±SD.
CR=Crunch training group; SC=Side crunch training group; LR=Leg raise training group.
* P<0.05 vs. Pre; † P<0.05 vs. CR; # P<0.05 vs. SC.

had significant increases in systolic and mean arterial blood pressures. The LR group showed superior increase in mean arterial pressure as compared with the CR and SC groups. A previous report had also shown the similar increment of systolic blood in two resistance training techniques of different intensity at the end of the last set of training (Moro *et al.*, 2011). Some studies reported that exercises with higher load significantly increase heart rate, systolic blood pressure and diastolic blood pressure (Terra *et al.*, 2008; Umpierre and Stein, 2007). In our study, significantly increased diastolic blood pressure was detected only in LR group. This protocol of training carried a higher load of the lower body weight throughout the period of training that might stimulate total body vascular resistance and lead to the higher changes in blood pressure.

Cardiovascular disease is one of the most common causes of death worldwide. The pathological change in the aorta and coronary artery is called "atherosclerosis". Endothelial dysfunction is an initial event of the atherosclerotic process and the correction of endothelial dysfunction has shown to reduce cardiovascular risk (Endermann and Schiffrin, 2004; Virdis *et al.*, 2010). The FMD has emerged as the non-invasive method for assessing and validating endothelial function in healthy individuals and cardiovascular disease patients (Corretti *et al.*, 2002; Mitranun *et al.*, 2014; Stoner *et al.*, 2012). Most of the studies of the long-term effects of exercise training showed the improvement of FMD and decreased risk of vascular impairment (Maiorana *et al.*, 2000; Mitranun *et al.*, 2014; Tjonna *et al.*, 2008; Wisloff *et al.*, 2007), whereas the effect of single bout training on FMD was still unclear. Some reports indicated that one hour resistance training induced a decrease of FMD (Jurva *et al.*, 2006), while the other study of one hour aerobic exercise at 60% of maximum oxygen consumption showed significantly enhanced FMD in post-menopausal subjects (Harvey *et al.*, 2005).

Vascular function tests on the resistance exercise training in one report has shown a negative outcome (Rakobowchuk *et al.*, 2005) while some investigators showed the opposite results (Cortez-Cooper *et al.*, 2005). Therefore, the effect of this type of training is still uncertain. The abdominal trainings, the resistance training from body weight were applied in our study. The CR group showed an increment of shear rate and blood flow. In one previous study of resistance training, the progressive intermittent handgrip exercise and knee-extensor training exercise at a work rate of 60% of maximum were found to have the same increments in shear stress as measurement through shear rate in the brachial artery and common femoral artery (Wray *et al.*, 2005). Shear stress presented as shear rate is the force from blood flow that applied on vascular wall. Shear stress activates endothelial nitric oxide synthase (eNOS) leading to a production of nitric oxide (NO) and results in vascular dilation (Deanfield *et al.*, 2005). It is possible that higher shear stress during the exercise bouts have induced higher responses at the cellular and molecular level on endothelial function (Wisløff *et al.*, 2007). FMD reflects the response of endothelial function to shear stress acting via the release of NO, prostacyclin, and endothelial-derived hyperpolarizing factor (Clifford and Hellsten, 2004). However, endothelial function is a systemic state of endothelial cells defined as a balance between vasodilating and vasoconsticting substances produced by endothelial cells (Deanfield *et al.*, 2005). For the SC group in our study, we found a significantly increased shear rate but no significantly increased FMD. This may be explained by the release of vasoconstricting substances, especially reactive oxygen species (ROS), during the acute exercise training causing damage to the membranal-polyunsaturated fatty acid (lipid peroxidation) of endothelial cells (Radak *et al.*, 2013). This mechanism may produce a greater magnitude of vasoconstricting effect over the vasodilating effect which is activated via the shear stress. Thus, in summation of both effects, the vascular dilation might not occur.

Interestingly, the LR group showed a decreased FMD despite having the increased shear stress and blood flow. This finding was similar to the previous studies in healthy subjects who performed handgrip exercise training (Gonzales *et al.*, 2010) and weight training (Varady *et al.*, 2009). The decreased FMD can be explained by the accumulation of ROS which results in the suppression of NO production from the endothelial cells (Giles *et al.*, 2012). The impairment of NO production results in the inability of arteries and arterioles to dilate.

Another mechanism responsible for the reduction of FMD in the LR group may relate to the increased blood pressure. The LR group performed leg raise training which burdened the body weight of lower part of the body to resist the muscle strength. This movement generates a higher blood pressure as compared to the other programs. In addition, the LR group also showed an increase in arterial stiffness through the significant increment of vascular resistance and the decrement of vascular conductance. The LR group might be a potent abdominal training to affect vascular tone and activate the sympathetic nervous system leading to vasoconstriction (Pratley *et al.*, 1994). A continuous augmentation of blood pressure impairs arterial elasticity, level of elastin (London and Guerin, 1999) and NO release (Bilfinger and Stefano, 2000). Acute rising in blood pressure diminished endothelium-dependent vasodilation in both hypertensive patients and subjects with normal blood pressure (Millgård and Lind, 1998). Although the LR group generated significant shear stress and blood flow, LR exercise may not be sufficient to overcome the combination of vasoconstrictive substances and higher blood pressure effects. Therefore, the overall result showed a reduction of FMD.

The subjects in this study were inactive persons, so the results might be different in active individuals. The decrement of FMD after acute exercise might be lower in active persons (Phillips *et al.*, 2011). Resistance training, 2-3 sets/ 6-8 repetitions maximum acutely impaired endothelial function in inactive subjects but not in the regular resistance-training subjects (Jurva *et al.*, 2006). Long-term exercise induces improvement of nitric oxide and antioxidant productions (Mitranun *et al.*, 2014).

In summary, the abdominal training is recommended to improve the strength of core muscles. All groups of training showed the increased blood pressure and shear stress. The CR showed the positive effects on vascular tone while the LR was not. For inactive individuals, we recommend to perform crunch training at the beginning of training for preventing an endothelial dysfunction state. After the vascular adaptation, the other postures might be added to the exercise program to improve the core muscle strength of the abdomen.

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