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Original Article

The acute effects of short and long durations of plank training on endothelial function

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Abstract

To investigate the acute effects of short and long durations of plank exercise training on the endothelial function (flow-mediated dilatation, FMD), shear rate, blood flow, vascular resistance, heart rate and arterial blood pressure. Thirty-two healthy untrained (inactive) male participants were randomly allocated equally to Plank 30 s training (P30) group and Plank 60 s training (P60) group. Participants were requested to perform 30 s or 60 s per set for 3 sets. Both P30 and P60 groups showed significantly increased shear rate, blood flow, systolic blood pressure and heart rate as compared to the pre-training ($P<0.05$). Only the P60 group showed significant increased in mean arterial blood pressure. The mean arterial blood pressure and systolic blood pressure of the P60 group were significantly higher than the P30 group. There was a significant decreased FMD in P60 group as compared to pre-training and post-training of P30 group. No change in FMD was observed in P30 group. In conclusion, impaired endothelial function was observed in the long duration plank exercise in untrained participants.

Keywords: endothelial function, flow-mediated dilatation, Plank 30 s training, Plank 60 s training

1. Introduction

Endothelial cells have a crucial role in maintaining vascular tone and systemic blood pressure. Brachial artery flow-mediated dilatation (FMD) is a non-invasive method for evaluating endothelial function and nitric oxide (NO) dependent vasodilation (Betik *et al*; 2004; Tinken *et al.*, 2010). FMD represents an ability of conduit arteries to dilate through a shear stress stimulus in healthy populations. This parameter has a higher value in healthy populations as compared with clinical populations (Ras *et al.*, 2013; Shechter *et al.*, 2009). The low value (below median) of FMD has higher risk to develop cardiovascular diseases after 3 years follow-up (Shechter *et al.*, 2009). The impaired FMD is associated with atherosclerosis of the coronary artery and clinical of congestive heart failure (Nagai *et al.*, 2013; Ras *et al.*, 2013). Endothelial dysfunction occurs early in the development of cardiovascular diseases and is associated with the future cardiovascular defense (Ras *et al.*, 2013). Clinically, FMD is also considered as risk stratification to predict cardiovascular events of myocardial infarction in patients with angina pectoris and prognostic parameter in patients with congestive heart failure (Flammer *et al.*, 2012).

Habitual exercise has beneficial outcomes on vascular endothelial functions through shear stress mechanism in healthy and clinical populations (DeSouza *et al.*, 2000, Mitranun *et al.*, 2014). An increment of shear stress enhances the change of vascular lumen via the activation of vasodilation and brought about the alteration in long-term FMD (Laughlin *et al.*, 2008). Nevertheless, the result is inconclusive in single bout exercise training. Dynamic low-intensity handgrip exercise has shown to improve FMD in healthy persons (Tinken *et al.*, 2009) whereas lower-extremity exercise (leg press exercise, 2 to 3 sets of 6 to 8 repetitions each to near maximal exertion) showed a decrement of FMD in inactive subjects (Jurva *et al.*, 2006). These results might relate

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to the slow contraction velocity which caused impaired FMD. There was no change in FMD in individuals that conducted fast contraction velocity (Gonzales *et al.*, 2010).

Low back pain may originate from the weakness of abdominal muscles (Walker *et al.*, 2000). Abdominal exercise is suggested to develop the muscle strength of trunk (D'Amico *et al.*, 2007). Plank or abdominal bridge is one of the best exercises recommended for the core muscle training. It builds isometric strength of the core muscles to help sculpt waistline and improve posture recommended in sport performance and rehabilitation (Imai *et al.*, 2010; Marshall and Murphy, 2005). This exercise posture provides an adequate stimulus of rectus abdominis and external oblique abdominis, which is of benefit to anterior core muscles for stabilizing and rehabilitation of the back (Ekstrom *et al.*, 2007), preventing back injury and low back pain (Handzel, 2003; Hill and Leiszler, 2011).

Abdominal trainings include both dynamic and isometric postures. Some of these trainings trigger a raise of blood pressure due to the Valsalva effect (Finnoff *et al.*, 2003). A recent study of dynamic postures showed that crunch training, an upper abdominal training, was effective on FMD while leg raise training, the lower abdominal training did not improve FMD (Mitranun and Phongsri; 2015). However, the effect of isometric postures on FMD is still unknown. The mechanical compression due to isometric exercise generated numerous increased systolic and diastolic pressures (MacDougall *et al.*, 1985). The inferiority of endothelial function was associated with lower diastolic blood pressure and higher pulse pressure during submaximal exercise intensity in healthy adolescents (Lambiase *et al.*, 2014). The purpose of this study was to investigate an acute effect of plank training on FMD and arterial blood pressure. Moreover, this study will convey the vascular function in different duration of plank exercise training.

2. Material and Methods

2.1 Participants

The participants were recruited from Srinakharinwirot University, Nakhon Nayok, Thailand. They were untrained and nonsmoking males who were 18-22 years of age. The inclusion criteria included healthy males, waist circumference of lower than 102 cm, body mass index (BMI) value of 18.5 to 24.9 kg/sq. m and had no previous exercise training program in the past 6 months. All participants were free from any recent injuries, cardiovascular disease and cerebrovascular disease. 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

A total of 32 male participants in this study were randomly allocated in equal numbers in to 2 groups: Plank 30 s training (P30) and Plank 60 s training (P60)

2.2 Exercise training programs

Both P30 and P60 groups underwent plank training for 3 sets and having a minute for resting between each set. Participants in the P30 started with a prone position on the mat. Both forearms were placed on the mat, both elbows bent 90 degrees and the elbows aligned directly beneath the glenohumeral joint. The whole body was then pressed up on the forearms and toes (dorsiflexion). The whole body from shoulders to ankles was kept in as straight a line as possible and the position held for 30 s in each set for the P30 group, and for 60 s in each set for the P60 group (Figure 1).

2.3 Measurements

All participants were asked to measure the biological data, flow-mediated dilatation data, and blood pressure data at two hours after having breakfast. Flow-mediated dilatation and blood pressure were repeated instantly after the last set of training.

2.4 Biological measures

Biological data consisted of the values of age, body mass, height, body mass index, body fat, heart rate at rest, systolic blood pressure, diastolic blood pressure, mean arterial pressure (MAP), and abdominal strength. Body fat was measured by using a body composition analyzer (Omron BF511, Omron Healthcare Europe B.V., Hoofddorp, Netherlands). All participants were asked to perform in the supine position for at least 5 minutes as a resting period prior to the measurement. The heart rate and blood pressure were measured by using digital blood pressure (Omron M2, Omron Healthcare Europe B.V., Hoofddorp, Netherlands) at baseline and instantly after the last set of training. The MAP was calculated by 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 maximum (1RM) method.

Figure 1. Plank training.

2.5 Flow-mediated dilatation measures (FMD)

The ultrasound equipment (SonoAce X6, Samsung Medison, Korea) was used to collect brachial characteristics, using the arterial occlusion technique on the right forearm. All participants were asked to perform in the supine position comfortably for 20 min and blood pressure cuff was placed around the right forearm throughout measurement. The brachial artery characteristics were imaged above 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 rapidly to 50 mmHg above systolic blood pressure. Mean blood velocity in all periods were measured on the pulsed wave Doppler mode. In order to diminish the investigator bias in the image analyses, computer-based analysis program (Brachial Analyzer, Medical Imaging Applications, Coralville, IA, USA) was used for analyzing changes on brachial diameter. Shear stress presented as shear rate was calculated by blood velocity/vascular diameter (Pyke *et al.*, 2008). FMD was calculated using the formula FMD = (maximum diameter – baseline diameter) x 100/baseline diameter. Brachial vascular conductance was calculated as brachial blood flow/mean arterial pressure, and brachial vascular resistance was calculated as mean arterial pressure/brachial blood flow (Mitranun and Phongsri, 2015).

2.6 Statistical methods

The data are shown as mean ± standard deviation. The dependent sample t-test was used to determine the significant within groups and the independent sample t-test was used to determine the significant between both groups. A level of $P<0.05$ was considered to be a significant difference.

3. Results

The baseline data of participant characteristics are shown in Table 1. Both P30 and P60 groups showed similar in number, age, height, body mass, body mass index, body fat, heart rate at rest, systolic blood pressure, diastolic blood pressure, mean arterial pressure, and abdominal strength.

The changes in the brachial characteristics and blood pressure data are shown in Table 2. Both P30 and P60 groups had significantly increased shear rate, blood flow, systolic blood pressure and heart rate as compared to the pre-training ($P<0.05$). Only the P60 group showed significantly increased mean arterial blood pressure. The mean arterial blood pressure and systolic blood pressure of the P60 group were significantly higher than those of the P30 group.

Table 1. Baseline data of participant characteristics.

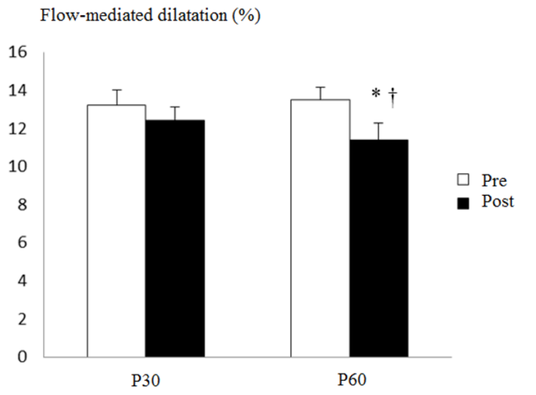
	P30	P60
Number (n)	16	16
Age (y)	20.1±0.6	19.8±0.5
Height (cm)	172.7±1.2	173.7±1.1
Body mass (kg)	69.6±1.5	70.2±0.9
Body mass index (kg/m^2)	22.8±1.2	23.0±0.9
Body fat (%)	18.7±1.7	18.6±1.6
Heart rate at rest	75.6±3.1	74.4±2.6
Systolic blood pressure (mmHg)	116.8±3.2	118.4±4.0
Diastolic blood pressure (mmHg)	78.6±2.8	80.1±2.4
Mean arterial pressure (mmHg)	91.9±1.9	92.5±2.4
Abdominal strength (kg)	32.6±1.8	33.3±2.0

Data are mean ± SD.
P30=Plank 30 s training group; P60=Plank 60 s training group.

Table 2. Brachial characteristics and blood pressure data

	P30		P60	
	Pre	Post	Pre	Post
Baseline brachial diameter (mm)	4.60±0.71	4.60±0.71	4.57±0.58	4.57±0.58
Peak brachial diameter (mm)	5.21±0.48	5.17±0.53	5.19±0.45	5.09±0.52
Shear rate (s^{-1})	39.4±1.5	42.4±1.1*	37.6±1.9	42.0±1.4*
Blood flow (ml/min^{-1})	235.4±4.7	249.7±4.0*	230.0±5.1	250.2±4.9*
Systolic blood pressure (mmHg)	116.8±3.2	125.0±3.0*	118.4±4.0	135.0±2.9*†
Diastolic blood pressure (mmHg)	78.6±2.8	76.5±2.2	80.1±2.4	82.5±2.6
Mean arterial pressure (mmHg)	91.9±1.9	92.8±1.4	92.5±1.8	100.1±1.9*†
Vascular resistance (AU)	0.41±0.01	0.40±0.04	0.41±0.02	0.41±0.01
Vascular conductance (AU)	2.49±0.11	2.61±0.13	2.43±0.08	2.48±0.09
Heart rate (beat/min)	75.6±3.1	108.4±3.4*	74.4±2.6	113.8±3.0*

Data are mean ± SD.
P30=Plank 30 s training group; P60=Plank 60 s training group.
* $P<0.05$ vs. Pre, † $P<0.05$ vs. P30.



P30= Plank 30 s training group; P60= Plank 60 s training group.
* P<0.05 vs. Pre, † P<0.05 vs. P30.

Figure 2. Flow-mediated dilatation.

Figure 2 shows the flow-mediated dilatation (FMD) in the both P30 and P60 groups. There was a significant decreased FMD in P60 group as compared to pre-training and post-training of P30 group. No change in FMD was observed in P30 group.

4. Discussion

Plank, isometric training of core muscles, is widely recommended to apply in weight losing program, body shape up, and prevention of low back pain (Ekstrom *et al.*, 2007; Stensvold *et al.*, 2010). Plank exercise program is concentrated mainly on the core muscles and partly on the limb muscles (Ekstrom *et al.*, 2007). Performing plank near fatigue exertion was recommended by many exercise instructors. To our knowledge, there was no previous study of hemodynamic effects on different durations of plank exercise. In this study we designed the experiment on two groups of plank exercises of different duration, P30 and P60, to observe the hemodynamic and FMD changes. The results may be used as a guideline to protect against adverse effects. Both plank 30 s (P30) and plank 60 s (P60) groups showed significant increases in systolic blood pressure and mean arterial blood pressure as compared to baseline. The P60 group showed a higher increment in both systolic and mean arterial blood pressures as compared to P30 group. A previous study also showed an increase of systolic blood pressure in resistance training techniques of different intensity at the end of the last set of training (Moro *et al.*, 2011). Exercises with higher load might induce increments of heart rate, systolic blood pressure and diastolic blood pressure (Terra *et al.*, 2008; Umpierre and Stein, 2007). Isometric exercise might generate a potent magnitude to increase blood pressure through the activation of mechanosensitive and metabosensitive muscle afferents (Maior *et al.*, 2014: Iellamo, 2001). The acute effects of abdominal exercise can trigger the Valsalva maneuver leading to a raise of systemic blood pressure. (MacDougal *et al.*, 1985; Finnoff *et al.*, 2003). The systolic blood pressure and mean arterial pressures were significantly higher in P60 group than P30 group. Thus, the longer duration of plank exercise might contribute to a higher activation and result in the undesirable effects on blood pressure.

Endothelial dysfunction is an initial event of the atherosclerotic process which increases cardiovascular risk (Endermann and Schiffrin, 2004; Virdis *et al.*, 2010). Habitual exercises were discovered to enhance endothelial function by increased antioxidant (Mitranun *et al.*, 2014), improved endothelial nitric oxide synthase (eNOS) and decreased inflammatory substances (Plaisance and Grandjean, 2006; Touati *et al.*, 2011) in both animal and human studies. The FMD has emerged as a 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). Long-term exercise training showed an 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. Jurva and colleague (2006) performed one hour of resistance training and the result showed the impairment of FMD (FMD change = -4.7 %). However, another report indicated that one hour of aerobic exercise at 60% of maximum oxygen consumption resulted in an improvement of FMD (FMD change = +6.8 %) in post-menopausal subjects (Harvey *et al.*, 2005). In the present study, FMD did not show a significant change in the P30 group while the P60 group showed significantly impaired FMD (FMD change = -2 %). A study of local vascular function in an acute exercise showed significantly reduced FMD following slow contraction but no change following fast contraction in inactive persons (Gonzales *et al.*, 2010).

Shear stress is considered as a substantial regulator of endothelial function. Low level of shear stress is associated with the development of cardiovascular diseases (Malek *et al.*, 1999). An increment of shear stress stimulates the calcium channel on the vascular endothelium, triggering via several cascades and resulting in higher NO production (Malek *et al.*, 1999; Gielen *et al.*, 2010). Plank exercises of P30 and P60 generated a significant increase in shear stress which was represented as a mean shear rate. Even though the increment of mean shear rate is supposed to improve FMD, it did not occur in either of our study groups. The variation of shear rate patterns (antegrade shear rate, retrograde shear rate, mean shear rate, oscillatory shear index) gave different responses to different types of exercise (Simmons *et al.*, 2011; Tinken *et al.*, 2009). Increased antegrade brought about the positive effects on vascular function, whereas retrograde and oscillatory shear rates gave the opposite result (Birk *et al.*, 2012; Thijssen *et al.*, 2009). We believe that longer duration of exercise might have generated higher retrograde and oscillatory shear rates which resulted in the impaired FMD in the P60 group.

The FMD values in both P30 and P60 groups may have resulted from the summation and competition of vasoconstricting and vasodilatating effects. Despite the increment of mean shear rate observed in P30, it may not be adequate for overcoming the effect of vasoconstricting substances, especially reactive oxygen species (ROS), during the acute exercise training that causing damage to the membranal-poly-unsaturated fatty acid (lipid peroxidation) of the endothelial cells (Radak *et al.*, 2013). Eventually, the summation outcome in P30 showed an unchanged FMD. The vasoconstricting effect in P60 may have overcome the augmentation of mean shear rate which resulted in a decreased FMD. The decreased FMD in P60 may be associated with two additional factors; the increased blood pressure and the increased oscillatory shear rate. The continuous augmentation of blood pressure impaired arterial elasticity, level of elastin (London and Guerin, 1999) and NO production (Bilfinger and Stefano, 2000). Acute rising in blood pressure diminished endothelium-dependent vasodilatation in both hypertensive patients and subjects with normal blood pressure (Millgård and Lind, 1998). The augmented oscillatory shear rate resulted in the alpha-adrenergic vasoconstriction (Casey *et al.*, 2012). Therefore, the summation effects showed a reduced FMD. We believe that the long duration of plank exercise might not be appropriate for inactive untrained individuals.

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

In summary, Plank is recommended to improve the strength of core muscles. All groups of training showed the increased blood pressure and shear stress. For inactive individuals, we recommend to perform Plank for 30 seconds at the beginning of training for preventing of endothelial dysfunction. After the vascular adaptation, the longer duration might be added to the exercise program to improve the core muscle strength of the abdomen.

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