

# A Single Bout of Exercise Reduces Postprandial Lipemia but Has No Delayed Effect on Hemorheological Variables

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## Abstract

High plasma triglyceride (TG) concentration in fasting state could cause hemorheological abnormality, thus increasing the incidence of metabolic diseases. Exercise has been reported to effectively reduce postprandial TG response. This study aimed to investigate whether a single bout of pre-prandial exercise can affect lipemia and hemorheological variables after a high-fat meal. Nine healthy young male subjects completed two experimental trials. The subjects walked for 1 h at 50% maximal oxygen uptake ( $\dot{V}O_{2max}$ ) (the exercise, EX trial), or rested (the control, CON trial). In the next morning, the subjects consumed a high-fat meal, and the postprandial lipemia and hemorheological responses were monitored for 6 h. The results showed that postprandial plasma TG concentrations were significantly lower in the EX trial compared to the CON trial. The postprandial low-density lipoproteins (LDL) concentration declined in the first 2 h and then gradually returned to the baseline level in both trials. The postprandial blood viscosity also decreased in the CON trial. There was no significant difference in postprandial blood viscosity, red blood cell (RBC) deformation index and aggregation degree between the trials. There was no significant correlation between plasma TG concentration and blood viscosity. In conclusion, brisk walking effectively reduced postprandial TG concentration, but has no significant impact on postprandial blood viscosity, RBC deformation index and RBC aggregation index.

**Key Words:** blood viscosity, endurance exercise, erythrocyte aggregation degree, hemorheology, high-fat meal

## Introduction

Hemorheology, or blood rheology, is the study of flow properties of blood and plasma elements and cells. Recent studies have shown that hemor-

heological abnormalities, including increases in plasma and blood viscosity and red blood cell (RBC) aggregation and the decrease in RBC deformability, may increase the incidence of metabolic disorders and cardiovascular diseases (14, 15, 27). Hemor-

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hemorheological abnormalities may influence hemodynamic disturbances that facilitate the process of acute thrombotic events and atherosclerosis (16). To develop strategies for reducing hemorheological abnormality is, therefore, much in need.

High plasma triglyceride (TG) concentration is regarded as one of the main causes for hemorheology abnormalities (6, 31). Postprandial hyperlipidemia, a disorder of occurrence of high concentrations of emulsified fats in the blood after a meal, has also been found to be a direct cause for increased aggregation of RBC that leads to poor local blood circulation (25, 29). In the long run, poor circulation could increase the risk for cardiovascular disease (24). As the postprandial lipemia phenomenon may last more than six h, people are in the postprandial state most of the time in a day. Therefore, it is of interest to reduce hemorheology abnormality by alleviating postprandial lipemia.

Exercise has been shown to prevent cardiovascular and metabolic diseases by a variety of mechanisms (13, 22). However, the impact of exercise on hemorheology is yet to be elucidated. In cross-sectional studies, trained athletes tended to have more ideal hemorheological state compared to untrained people (7, 20). A meta-analysis also showed that exercise training improved hemorheology in sedentary subjects (22). However, the acute effect of exercise on hemorheology is still under investigation.

Previous studies have shown that delayed effects of a single bout of endurance exercise on the day before a high-fat meal (8-16 h after exercise) could reduce postprandial lipemia (4, 21). The possible mechanism that acute exercise decreases postprandial lipemia has been attributed to several factors including increased activity of lipoprotein lipases in the muscle (12, 23), increased postprandial fat oxidation rates and decreased release of very-low-density lipoprotein (VLDL) in the liver (11). Studies have also shown that elevated plasma TG concentration was one of the main factors for hemorheological abnormalities (6, 31). It is still not known if reduction in postprandial TG concentration by exercise may further improve postprandial hemorheology. The aim of this study was to investigate the relationship between postprandial lipemia and hemorheology, and the impact of exercise intervention.

## Materials and Methods

### Subjects

Nine healthy young male subjects (age:  $23.8 \pm 0.2$  years old; height:  $1.72 \pm 0.02$  m; weight:  $69.8 \pm$

$1.5$  kg) who were engaged in recreational physical activities but never underwent training of any sport were recruited. All subjects were non-smokers, non-drinkers, and were free of known metabolic diseases. Their fasting blood lipid concentrations were within the normal range. All subjects were fully explained the experimental procedure and risk before signing the informed consent. This study was approved by the Human Ethical Committee of National Taiwan Sport University.

### Pretest

One week before the first trial, all subjects participated in a submaximal and a graded maximal exercise test to calculate the exercise intensity that represented 50% maximal oxygen uptake ( $\dot{V}O_{2max}$ ). The two tests were completed on the same day with a 40- to 50-min rest in between.

(a) Submaximal exercise test. The subjects selected the comfortable walking speed at 5-6 km/h on a motorized treadmill (Medtrack ST65, Quinton, Seattle, WA, USA). The slope began at 0 degree then gradually increased by 2.5 degrees every 3 min in a total of four stages. The breath-by-breath gas analysis was performed by a gas analyzer (Vmax Series 29C, SensorMedics, California, USA).

(b) Graded maximal exercise test. According to the abilities of the subjects, the speed was set between walking and running at 6-7 km/h. The slope began at 0 degree then gradually increased by 2.5 degrees every 3 min until volitional fatigue was reached. The expired gas was collected and analyzed for oxygen consumption ( $VO_2$ ) and carbon dioxide production ( $VCO_2$ ). The results from these two tests were used to calculate the exercise intensity corresponding to 50%  $\dot{V}O_{2max}$ . The energy expenditure of 1 h of exercise at 50%  $\dot{V}O_{2max}$  was calculated according to Frayn (9).

### Experimental Procedure

All subjects completed two 2-day trials in a randomized order. The two trials were separated by at least 1 week. Three days prior to the trial, all subjects were asked to avoid any vigorous physical activity. The subjects kept a food journal during the three days prior to the first trial, then repeated the same diet before the next trial. In the first day of the trial, the subjects reported to the laboratory at 4 pm. They either walked on a treadmill for 1 h at the intensity representing 50%  $\dot{V}O_{2max}$  (designated as the exercise, or EX trial), or remained seated for 1 h (the control, CON trial). After exercise or rest, the subjects rested for 2 h in the laboratory without ingesting any drink or food except water. The

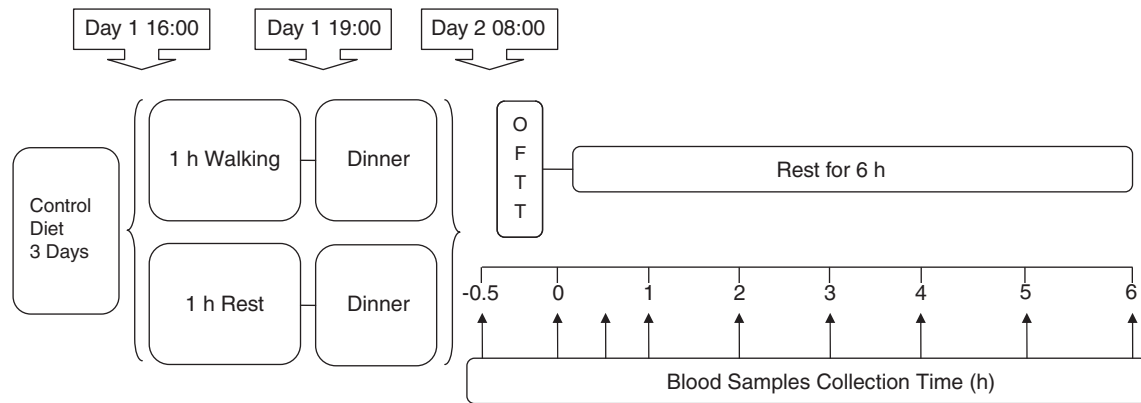


Fig. 1. Study design of the present work. Subjects completed three experimental trials: in the EX trail, the subjects were asked to perform the exercise of 1-h 50%  $\dot{V}O_{2\max}$  walking in the afternoon of the first day of the experiment; in the control trial, subjects were rested. In the next morning of the experiment, the subjects were given a high-fat meal and blood samples were collected at the time points indicated by the upward arrows ( $\uparrow$ ). OFTT: oral fat tolerance test.

subjects then consumed a standard dinner with 692 kcal; 50% energy from carbohydrate, 32% from fat, and 18% from protein. After an overnight fast, the subjects returned to the laboratory in the morning on the second day. Fasting blood samples were taken by an indwelling cannula. The oral fat tolerance test (OFTT) meal was then served. The subjects had to finish the meal within 20 min, and rested in the laboratory for 6 h without any unnecessary physical activity. The experimental procedure is shown in Figure 1.

#### OFTT

The OFTT meal consisted of bread, butter, cheese, wheat and cream, providing 1.2 g/kg fat, 1.1 g/kg carbohydrate, 0.33 g/kg protein and 16.5 kcal/kg (3) of body mass. All foods were purchased from a local supermarket and the nutrient contents were based on the label on the package.

#### Blood Collection

All blood samples were taken from a cannula (Venflon 20G, Stockholm, Sweden) with a three-way connector (Connecta Ltd., Stockholm, Sweden). Ten milliliters of the blood sample was taken in each of the time point: before the meal, and 30, 60, 120, 180, 240, 300 and 360 min after the meal. The blood samples were immediately put into tubes containing ethylenediaminetetraacetic acid (EDTA) and analyzed for hematocrit and hemoglobin by a cell counter (Sysmax KX-21N, Kobe, Japan). Subsequently, 2 ml blood was set aside and the remaining samples were centrifuged at  $500 \times g$  for 20 min at 4°C. Plasma samples were aliquoted and immediately

stored in a -80°C freezer for analysis later.

#### Blood Biochemical Analysis

Plasma TG, high-density lipoprotein cholesterol (HDL-C) and total cholesterol (TCHO) were analyzed by an automatic biochemical analyzer (7020, Hitachi, Tokyo, Japan) using commercial kits (Randox, Antrim, UK). Plasma LDL cholesterol (LDL-C) concentration was calculated according to Friedewald *et al.* (10).

#### Blood Hemorheological Analysis

Hemorheological parameters were analyzed according to previously published methods (23). Blood viscosity was analyzed by a rheometer (Rheostress 1 double cone viscometer, HAAKE Mess-Technik, Karlsruhe, Germany). For blood samples, the hematocrit was adjusted to 45% plasma and 55% RBC with the plasma from the same subject. The temperature was set at 37°C under the conditions of shear rates at 75 and 525 mPa. The different shear rates reflect the different velocities of flow in the blood vessel (17).

Erythrocyte deformability was analyzed by a laser-assisted optical rotational cell analyzer (LORCA, RR Mechatronics, Hoorn, Netherlands) (25). RBC were added to phosphate-buffered saline containing 5.5% polyvinylpyrrolidone and heated to 37°C. Then, 0.7 ml diluted solution was added to the translucent U-shaped plastic beam traverses under 30 Pa pressure and irradiated by the laser light. A computer program calculated the length of the long end of the oval RBC as A, and the length of the short end as B. The RBC deformability index (DI)

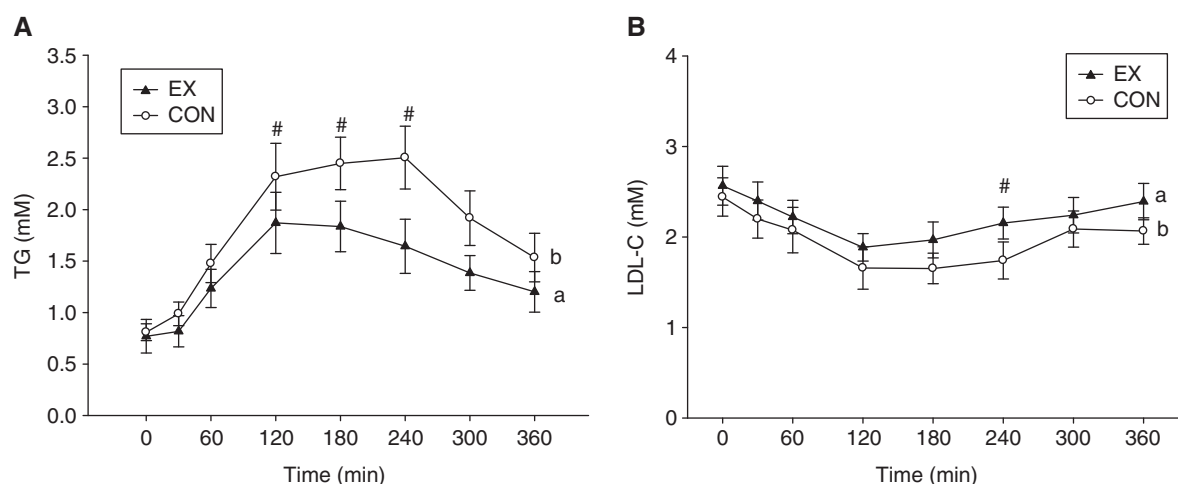


Fig. 2. Postprandial plasma TG concentrations (A) and LDL-C (B) in the EX (▲) and CON (○) trials. Values are mean  $\pm$  standard error of the mean (SEM),  $n = 9$ . #Significantly different between the trials ( $P < 0.05$ ); a, significant time effect ( $P < 0.05$ ) in the EX trial; b, significant time effect ( $P < 0.05$ ) in the CON trial. TG: triglyceride.

was calculated as  $DI = (A - B)/(A + B)$ . Erythrocyte aggregation was analyzed by using laser diffraction plus syllectogram kinetic parameters (LORCA, RR Mechatronics, Hoorn, Netherlands). First, 0.5 ml EDTA-containing blood was added to U-shaped plastic beam traverses. The image was presented in a computer by using laser irradiation, and the RBC aggregation degree was obtained by using the syllectogram analysis method.

#### Statistical Analysis

All data were presented as mean  $\pm$  standard errors. Plasma biochemical and hemorheological parameters were analyzed by two-way analysis of variance (ANOVA) with repeated measures. The Bonferroni method was used to detect the difference between groups or time points if the main and interaction effects were significant. The significant level was set at  $P < 0.05$ .

## Results

### Blood Biochemical Parameters

Plasma TG concentrations were significantly lower in EX compared to CON at 120, 180 and 240 min during the postprandial period ( $P < 0.001$ ). Plasma LDL-C concentration decreased during the first 2 h after the high-fat meal, then gradually returned to the baseline in both trials. There was a significant difference between trials at 240 min (Figs. 2A and 2B).

### Blood Viscosity

The blood viscosity at high and low shear rates reflect different velocities of blood flow in large and small vessels, respectively. Under the two shear rate conditions, blood viscosity significantly declined in the postprandial period in the CON trial. However, a *post hoc* analysis did not reveal any significant difference between any two time points. Blood viscosity remained unchanged during the postprandial period in the EX trial. There were no significant differences between the two trials at any time point (Figs. 3A and 3B).

### Degrees of RBC Deformation and Aggregation

RBC deformity index and aggregation remained unchanged during the postprandial period (Figs. 4A and 4B, respectively) in both trials. The exercise in the previous day did not result in any difference in these two parameters after the high-fat meal.

## Discussion

Data of this study suggested that a single high-fat meal and exercise did not affect blood viscosity. In this study, the high-fat meal induced high postprandial TG response, and 1-h walking was effective in reducing postprandial lipemia. However, blood viscosity was similar between the two trial groups indicating that factors other than TG would affect postprandial blood viscosity. In addition, a single high-fat meal with or without previous exercise did not affect RBC deformability and degree of aggregation.

The current data also suggested that a single postprandial high TG response might not be the

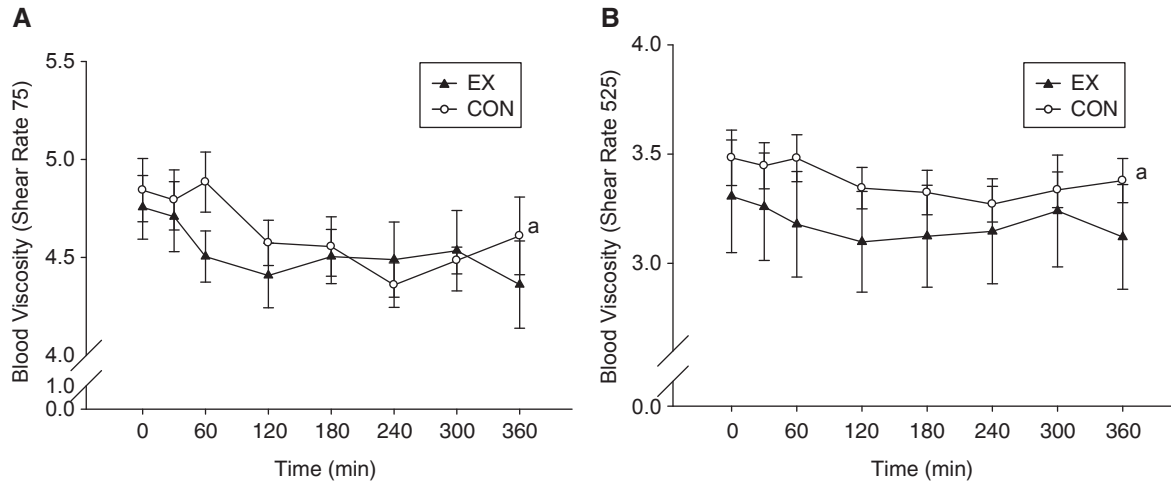


Fig. 3. Fasting and postprandial 6 h of blood viscosity under the condition shear rates of 75 and 525 mPa on the CON (○) and EX (▲) trials. Values are mean  $\pm$  SEM,  $n = 9$ . a, significant time effect ( $P < 0.05$ ) in the CON trial.

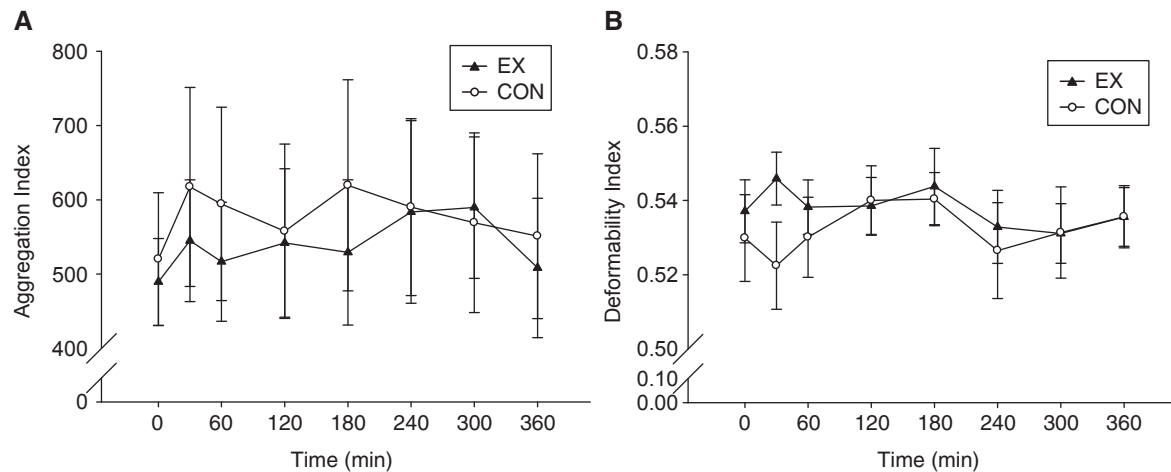


Fig. 4. Fasting and postprandial 6 h of degrees of RBC deformation and aggregation on the CON (○) and EX (▲) trials. Values are mean  $\pm$  SEM,  $n = 9$ .

major factor influencing blood viscosity. In agreement, previous studies also found that a high-fat meal did not affect blood viscosity during a 2-h postprandial period (4, 5, 18). Cicha *et al.* reported that both high- and low-fat meals resulted in similar blood viscosity despite significant difference in TG concentrations (5). Unlike the present study, Cicha *et al.* (5) used the native hematocrit at 25°C to measure blood viscosity. As hematocrit is an important factor of blood viscosity, hematocrit of all samples in this study was adjusted to 45% before being tested at 37°C, which was similar to the normal human hematocrit and body temperature. Even though we improved the methodology of measuring blood viscosity, the blood viscosity remained stable after a

high-fat meal with or without previous exercise. It is unlikely that a single high-fat meal would affect blood viscosity during the postprandial period.

This study showed that a single high-fat meal did not affect the capacity of RBC deformation. To our knowledge, there is no literature exploring the impact of a single high-fat meal on RBC deformation capacity. However, it has been revealed that a long-term high-fat diet would impair RBC deformability (25), therefore reducing the capacity of RBC to pass through the micro blood vessels. The main reason for the decreased deformability could be the increases in cell membrane cholesterol (8) and oxidative stress (25). In addition, it has been found that patients with high cholesterol concen-



trations showed poorer RBC deformation capacity (2). Cholesterol-lowering drugs also resulted in an increase in RBC deformability by reducing the cholesterol content in the RBC cell membrane (19, 29). However, modifications in the cholesterol content in the RBC membrane require a longer period of time, which may be the reason for the lack of effects of a single meal.

The postprandial erythrocyte aggregation remained unchanged in both trials. Previous studies have shown significantly positive correlations between blood TG concentration and RBC aggregation (4, 5, 18). However, only one subject was investigated in these studies, making the results less convincing. Our results indicated that a single high-fat meal did not result in changes in erythrocyte aggregation in young, healthy and active subjects with or without prior exercise.

The current data suggested that the 1-h walking did not alter the hemorheological variables at the fasting and postprandial states on the following day. Most previous studies investigated the acute effects of exercise, *i.e.* the changes between pre-exercise and immediately after exercise. Studies showed that hemorheological impairments were observed after a single bout of exercise (1, 30). Some scholars suggested that the abnormality might be due to dehydration from exercise; hence, the hemorheological changes usually do not last long and disappear after fluid replacement (26). Nevertheless, the health benefit from exercise has been suggested to have the phenomenon of “delay effect” (28). To our knowledge, the present study is the first to reveal the delay effects of exercise on the hemorheologic variables.

In conclusion, postprandial lipemia phenomena after a single high-fat meal was attenuated by endurance exercise in young and healthy men, and the effect was accompanied by a slight decline in blood viscosity. The high-fat meal resulted in a decrease in blood viscosity that may be mediated by factors other than high TG concentrations. In addition, a single high-fat meal with or without prior exercise had no impact on RBC deformability and aggregation. Further studies on long-term high-fat diets and exercise on the impact of hemorheology and the underlying mechanism are warranted.

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### Conflict of Interest

The authors declare that they have no compet-

ing interests.

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