Metabolism Open 16 (2022) 100216

Contents lists available at ScienceDirect

Metabolism Open

journal homepage: www.sciencedirect.com/journal/metabolism-open

Effects of short-term pistachio consumption before and throughout recovery from an intense exercise bout on cardiometabolic markers

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ARTICLE INFO

Keywords:
Pistachio
Nut
Metabolic health
Athletes
Cholesterol

ABSTRACT

Although pistachios have been shown to improve cardiometabolic biomarkers in diseased and at-risk populations, less research has been conducted on young, healthy individuals. Furthermore, some but not all research indicates that exercise acutely improves cardiometabolic markers; however, it remains unclear as to why outcomes vary among studies. This research evaluated secondary aims of a study designed to assess the impacts of pistachios on recovery from vigorous eccentrically-biased exercise. Here we examined the short-term (two weeks) effects of two different doses (1.5 oz/d and 3.0 oz/d) of pistachios and a water-only control on the biomarkers of metabolic health in young adult men. This was followed by daily blood collection for three consecutive days after a 40-min downhill run. Twenty-seven participants completed each of three conditions in a counterbalanced randomized order. Plasma biomarkers (lipid profile, glucose, and insulin) were measured at the end of each 2-week feeding period immediately before the exercise bout and again 24, 48, and 72 h thereafter. Two weeks of pistachio consumption failed to elicit changes in any biomarker ($p < .05$).. Exercise reduced LDL-cholesterol at the end of the recovery period; however, positive effects were limited to when subjects were consuming the higher dose of pistachios. Follow up t-tests revealed significant reductions in LDL-C in the high dose group at 72-H compared to that at 0-H (8.2 ± 19.4; $p < .04$), 24-H (8.0 ± 18.6; $p < .04$), and 48-H (9.3 ± 15.8; $p < .005$) post exercise within the same trial. Overall, in healthy young men with normal blood lipid and glucose metabolism, little effect of either pistachios or intense exercise on cardiometabolic risk indicators was detected. More research is needed to determine the influence of usual diet consumption on outcomes following an acute exercise bout.

1. Introduction

Cardiovascular disease (CVD) remains one of the leading causes of death around the world, accounting for 32% of total deaths in 2021 [1]. This group of disorders is characterized by obstructions of blood vessels of the heart leading to impairments in blood circulation. Risk factors for the development of CVD include elevated blood glucose, dyslipidemia, hypertension, and overweight/obesity [1]. The Mediterranean diet, as characterized by high intake of nuts and seeds, has been shown to reduce the incidence of CVD events [2]. Nut intake has also been associated with improved risk factors for CVD development, as evidenced by improvements in blood glucose [3], lipid profile [4], blood pressure [5] and body weight [6,7]. Although less commonly studied, research suggests that pistachios provide similar benefits than those experienced from consumption of other nuts [4].

Metabolic syndrome (MetS) affects more than 30% of the US population [8]. MetS, which is strongly associated with the development of CVD and Type 2 Diabetes, refers to a set cluster of symptoms metabolic disorders strongly associated with the development of CVD and Type 2 Diabetes, including abdominal obesity, elevated blood glucose, dyslipidemia, and hypertension [9]. While some incidences of MetS are acquired genetically, most cases are likely a result of chronically high energy intake [9]. Insulin resistance and chronic inflammation (induced by obesity) appear to be the main stressors in the progression of MetS to

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https://doi.org/10.1016/j.metop.2022.100216
Received 2 September 2022; Received in revised form 19 October 2022; Accepted 20 October 2022
Available online 21 October 2022

CVD [9]. The Mediterranean diet, which has demonstrated success in improving CVD outcomes, has also been studied as a potential therapeutic diet for MetS [10]. In obese women, 2 months of Mediterranean diet consumption was shown to improve body composition and metabolic profile [10]. Furthermore, the Mediterranean diet supplemented with nuts was able to reverse MetS more than that of a low-fat diet in participants at high risk for CVD [10]. Pistachios alone have shown promise in improving MetS symptoms as well. In a meta-analysis by Baghery, pistachio consumption was shown to reduce systolic blood pressure, triglycerides, fasting blood glucose, and increased HDL-C [11]. These positive results warrant further investigation of pistachio consumption on metabolic profiles.

Pistachios are rich in protein, fiber, unsaturated fat, and micronutrients. Notably, they provide approximately 6 g of protein and 3 g of fiber in a one-ounce serving. Pistachios also contain high amounts of vitamin K, potassium, magnesium, γ-tocopherol, and phytochemicals [12]. The unique makeup of these nuts provide a satiating, low GI snack that has been associated with greater weight loss than an isocaloric, refined CHO snack [13]. Pistachios also are a source of plant sterols, which may contribute to lowered cholesterol in the blood [14]. Sterols compete with cholesterol for absorption in the intestinal lumen, and therefore decrease cholesterol uptake [15]. The systemic result is increased cholesterol synthesis by the body, which decreases circulating low density lipoprotein cholesterol (LDL-C) levels through upregulation of the LDL receptor [16].

The acute effects of aerobic exercise have been widely studied, but the effects on blood lipids are unclear. Exercise of as little as 15 min has been shown to increase HDL-C levels 10.8% in black female smokers, but these values returned to baseline within 10 min of exercise [17]. Gordon et al. [18] examined the effects of longer periods of exercise in moderately trained females (running at 75% VO2 max until 800 kcal was expended) and observed increases in HDL-C only at 48 h post exercise. In normolipidemic men, no differences were found for TC, TG, or LDL-C after 30 or 45 min of intense exercise. However, HDL-C was significantly higher at 24 h after 45 min of exercise than after 30 min of exercise [19]. Another study by Gordon et al. [20] indicates that exercise intensity may play a role in HDL-C changes. No changes in HDL-C were observed following exercise at 60% VO2 max; however, an increase in HDL-C was observed at 24 h after exercise at an intensity of 75% VO2 max. Although the acute effects of exercise show promise to positively affect blood lipids, specifically HDL-C, outcomes vary significantly between studies. Therefore it is important to understand the factors that may influence the differences in outcomes.

Previous studies have displayed pistachios' ability to improve lipids, glucose, and insulin levels in diseased populations [16,21,22]. However, little research has been done in demonstrating the effects these nuts have on healthy, athletic populations, or in conjunction with exercise. This study was designed to examine the effects of a randomized, two-week crossover study providing two different doses of pistachios on the biomarkers of metabolic health in healthy young adult men. It was hypothesized that two weeks of pistachio consumption would improve biomarkers in a dose-dependent manner, and lead to improvements in total cholesterol (TC), high density lipoprotein cholesterol (HDL-C), low density lipoprotein cholesterol (LDL-C), triglycerides (TG), glucose, insulin, and insulin sensitivity.

2. Methods

This randomized, crossover study was a part of a larger, multi-center study including both a North American arm, which took place at San Diego State University, and a European arm, which took place at the University of Stirling, Scotland. Identical methods were used between both arms of the study wherever possible. The North American arm was approved by the San Diego State University Institutional Review Board (Approval #HS-2018-0114).

Participants were recruited from San Diego State University and surrounding areas. Forty male subjects were recruited and enrolled. However, due to dropouts and COVID-19 related lockdowns, only 27 of these men completed all aspects of the study. Inclusion criteria required participants to be 18–25 years old, to be moderately active (exercise at least 5 h per week), and to actively participate in sport. They were excluded if they were smokers, or if they had taken any medications or dietary supplements known to impact inflammation or antioxidant status within 1 month of study enrollment.

Prior to initiation of their experimental trials, each participant completed a graded exercise test on a Lode Valiant Sport treadmill to determine their maximal oxygen consumption (VO2 peak). Participants were also familiarized with test protocols to minimize learning effects in subsequent trials.

The study consisted of 3 experimental trials, each separated by at least 3 weeks. Each trial consisted of a 40-min, moderately paced downhill run (65–70% VO2 peak, −10% grade), which took place after 2 weeks (14 days) of daily test food consumption. The test foods consisted of water (control), 1.5 oz/d shelled pistachios (low dose), and 3.0 oz/d shelled pistachios (high dose). Reminders were sent out bi-weekly via text to ensure compliance, and any remaining pistachios were returned to researchers on the day of the downhill run. Twenty-four hour food recalls were completed prior to exercise, and at 24, 48, and 72 h post exercise and analyzed via FoodProcessor (Version 11.9.13, ESHA Research, Salem, United States). These records were given back to participants, and they were asked to follow a similar diet for each downhill run and follow up day. A fasted blood draw was completed the morning of each test day. Plasma was analyzed via colorimetric kits for total cholesterol (TC), triglycerides (TG), HDL-C, and glucose (EKF Diagnostics, Boerne, TX). LDL-C was calculated using the Friedewald equation [23]. Insulin was determined using an ELISA assay (Alpco, Salem, New Hampshire), and insulin sensitivity was calculated using the QUICKIE method [24].

2.1. Statistical analysis

Data were analyzed using IBM SPSS Statistics 28. The assumptions of normality and homogeneity were assessed prior to analysis, and outliers were removed from the dataset if they fell further than 3.3 times the standard deviation from the mean. A 3 (trial) x 4 (time) repeated measures analysis of variance was utilized to analyze differences within and between trials. Paired T-tests were used to further investigate where specific differences occurred. A p value $\leq .05$ was considered statistically significant.

3. Results

Key participant demographics are summarized in Table 1. For the low dose trial (1.5 oz pistachios), 17 participants consumed 100% of test foods. Average consumption within the two-week period was 96%. For the high dose trial (3.0 oz pistachios), 18 participants consumed 100% of test foods. Average consumption for this trial was 95%.

Dietary intake was assessed to determine changes in nutrient consumption based on trial assignment. Table 2 displays the average daily intake based on the four 24-h recalls completed for each trial. As expected, consumption of either dose of pistachios led to increased daily kcal, protein, and fat intake. Consumption of the high dose of pistachios also caused increased daily fiber intake.

A significant main effect of time was found for LDL-C levels ($p < .02$). Follow up t-tests revealed significant reductions in LDL-C in the high dose group at 72-H compared to that at 0-H ($p < .04$), 24-H ($p < .04$), and 48-H ($p < .005$) post exercise within the same trial. No differences were found between trials or within the control or low dose trials. No main effects were observed for the other biochemical measurements (Table 3).

4. Discussion

In addition to being a healthy, nutrient rich snack, pistachios may enhance the beneficial effects of exercise on blood lipids. Our results suggest that acute exercise in conjunction with consumption of 3.0 oz of pistachios per day suppressed LDL-C levels 72-H after exercise. No significant impact of exercise or either dose of pistachios were detected for TC, TG, HDL-C, glucose, insulin or insulin sensitivity throughout the 72-H recovery period.

Based on prior literature, acute exercise has usually not been shown to influence LDL-C, TG, or TC in a similar population [19]. However, diet prior to and after exercise was not controlled, and may play a significant role in post exercise lipid metabolism. Our study suggests that consumption of 3.0 oz/d pistachios amplified the effects of exercise and led to improvements in LDL-C 72-H post exercise. Although the mechanism of action is unclear, it is possible that the unique nutrients found in pistachios led to positive improvements in metabolism and allowed exercise to exhibit its full potential benefits. Future research is needed to determine if other nuts have similar effects on blood lipids in conjunction with exercise.

Previous research provides compelling evidence of the beneficial effects of pistachios on metabolic biomarkers in diseased populations. Sabate et al. [4] reviewed the literature and concluded that nuts tend to promote improvements in blood cholesterol. These studies generally included overweight or metabolically impaired participants, indicating they were likely to have irregular baseline values for these markers. Statins, a popular cholesterol lowering medication, have been shown to take at least 2–3 months to produce improvements in cholesterol levels [20]. Due to the short intervention time of this study, it is feasible that pistachios were able to produce minimal improvements to cholesterol levels that could potentially be amplified over a longer study period. Furthermore, evaluating the effects of pistachios on a young, healthy population likely impaired our ability to determine beneficial effects. Since our population already had normal levels of TC, TG, HDL-C, and LDL-C, it is unlikely that dramatic improvements would occur. However, the moderate reduction in LDL-C observed at 72-H post exercise in the high dose group indicates that improvements are possible, even in this healthy population. Future studies implementing longer trial periods will help to solidify these findings.

Similarly, daily nut consumption has been shown to reduce fasting glucose and insulin levels in diabetic populations [3]. Blood glucose is one of the most tightly regulated systems in the human body, and fasted blood levels are maintained between 70 and 100 mg/dL in healthy individuals. Our participants were healthy non-diabetics, and all fasted glucose levels remained within these limits. Based on our measurements, it does not appear that pistachio consumption influenced glucose or insulin; however, a reduction in fasting glucose from the already healthy levels was not expected. It is possible that pistachio consumption may have led to benefits in glucose metabolism that were not detectable in our study, such as reduced spikes in postprandial glucose. The gold standard of measurement of average blood glucose is HBA1C, which measures the amount of glucose that is attached to hemoglobin. Unfortunately, since changes to HBA1C take up to 3 months to detect, these changes were not observable in our study. Future long-term studies will be able to better highlight these changes in glucose metabolism in healthy or unhealthy populations.

The results of this study are limited to young, moderately trained male athletes, so caution should be implemented when generalizing results. Future studies are necessary to examine the effects of pistachio consumption and exercise on a sample inclusive of females, older individuals, and less active individuals. Furthermore, our limited sample size may compromise our ability to see true differences between conditions. Had our study not been negatively impacted by the COVID pandemic, more participants likely would have been able to complete the study, which would have increased the statistical power of our results. Upcoming studies with larger sample sizes should be completed to confirm our findings and to add to the growing body of research in this field.

Overall, consumption of 3.0 oz/d pistachios was able to enhance the acute effects of exercise, and led to improvements in LDL-C levels 72-H after exercise. Our results suggest that pistachio consumption may improve the acute beneficial effects of exercise, although further studies are needed to support these findings.

Funding

This study was funded by the American Pistachio Growers (Grant #594108).

CRediT authorship contribution statement

Elise North: Data curation, Formal analysis, Visualization, Writing – original draft, Writing – review & editing. **Imogene Carson:** Data curation. **Stuart Galloway:** Writing – review & editing. **Mee Young Hong:** Funding acquisition. **Shirin Hooshmand:** Formal analysis, Funding acquisition, Project administration, Supervision, Visualization, Writing – original draft, Writing – review & editing. **Changqi Liu:** Funding acquisition. **Lauren Okamoto:** Data curation. **Timothy O'Neal:** Data curation. **Jordan Philpott:** Writing – review & editing. **Vernon Rayo:** Data curation, Visualization, Writing – original draft, Writing – review & editing. **Olly Witard:** Conceptualization, Funding acquisition, Writing – review & editing. **Mark Kern:** Conceptualization, Formal analysis, Funding acquisition, Project administration, Supervision, Visualization, Writing – original draft, Writing – review & editing.

Declaration of competing interest

The authors have no conflicts of interest to declare.

Acknowledgments

The authors would like to acknowledge the contributions of Kristine Giltvedt, Morgan Harris, Alfonso Munoz, Traci Roberts, Nicholas Smith, Jillianne Son, and Svitlana Storm, who assisted in conducting and evaluating this research.

Appendix

Table 1
Anthropometric characteristics

Descriptive Statistics (n = 27)	
Height (cm)	174.8 (6.5)
Weight (kg)	75.6 (11.2)
Age (years)	24 (4)
Body Fat (%)	20.6 (9.4)
Lean Body Mass (kg)	57.3 (6.3)
VO2 Max (mL/kg/min)	51.1 (8.4)

Data are represented in Mean (SD).

Table 2
Average Dietary Nutritional Intake

Nutrient Analysis (n=27)	C	1.5 oz	3.0 oz
Energy (kcal)	2120 (472)[a]	2424 (582)[b]	2452 (638)[b]
CHO (g)	237 (82)	267 (111)	257 (95)
Protein (g)	107 (30)[a]	119 (41)[b]	115 (33)[b]
Fat (g)	85 (23)[a]	99 (23)[b]	110 (26)[b]
Saturated Fat (g)	26 (9)	28 (12)	26 (9)
Fiber (g)	22 (13)[a]	27 (17)[a]	29 (16)[b]

Data are represented in Mean (SD). Within a trial, different superscripts indicate statistically significant differences ($p < .05$).

Table 3
Mean Biochemical Parameters Measured Across Time and Trial

	Control				1.5 oz				3.0 oz			
	0-H	24-H	48-H	72-H	0-H	24-H	48-H	72-H	0-H	24-H	48-H	72-H
Cholesterol (mg/dL)	134.5 (38.4)	136.5 (36.7)	136.9 (36.1)	131.3 (33.3)	132.0 (33.0)	130.3 (33.0)	128.8 (35.7)	131.2 (31.9)	132.3 (36.8)	130.4 (33.1)	131.4 (33.2)	124.6 (34.3)
TG (mg/dL)	67.9 (29.2)	64.6 (19.4)	69.3 (22.9)	69.5 (30.2)	67.8 (26.4)	69.4 (31.5)	78.0 (32.1)	69.2 (27.1)	72.9 (33.0)	68.8 (25.3)	65.4 (23.3)	67.9 (25.8)
HDL-C (mg/dL)	42.9 (11.2)	43.3 (10.5)	42.8 (10.3)	43.4 (8.7)	42.8 (9.9)	43.0 (10.9)	42.4 (9.8)	42.4 (11.7)	43.2 (9.8)	42.1 (8.9)	43.3 (9.9)	43.4 (11.5)
LDL-C (mg/dL)	77.3 (37.0)	80.8 (39.2)	83.4 (39.1)	77.4 (36.6)	75.8 (33.6)	76.1 (33.4)	76.8 (32.3)	75.3 (35.1)	77.1 (35.4)[a]	76.9 (33.7)[a]	78.2 (33.9)[a]	68.9 (38.0)[b]
Glucose (mg/dL)	87.5 (8.6)	89.4 (9.8)	87.8 (7.7)	87.3 (12.3)	88.8 (13.8)	90.4 (10.1)	88.9 (11.9)	88.4 (9.4)	87.0 (10.6)	88.7 (9.5)	85.9 (11.5)	86.3 (11.8)
Insulin (uIU/mL)	5.8 (2.6)	5.8 (3.5)	5.4 (2.8)	7.1 (4.9)	7.6 (5.1)	5.4 (3.3)	5.1 (2.5)	6.2 (3.5)	5.7 (2.9)	5.7 (3.1)	5.8 (3.0)	7.2 (4.4)
Insulin Sensitivity	.38 (.04)	.38 (.04)	.38 (.03)	.37 (.04)	.37 (.04)	.38 (.05)	.37 (.03)	.37 (.03)	.38 (.04)	.38 (.03)	.38 (.05)	.37 (.03)

Data are represented in Mean (SD). Within a trial, different superscripts indicate statistically significant differences ($p < .05$).

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