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Review

Nuts for Physical Health and Fitness: A Review

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Abstract: Nuts are rich in various nutrients. Recent evidence suggests that nut consumption has beneficial effects on blood pressure, lipid profile, obesity, inflammation, and oxidative stress, which reduce the risk of cardiovascular disease. Previous studies have shown that nut consumption improves body composition without causing weight gain, despite total energy intake increases. However, evidence regarding nut consumption and physical fitness is limited. The aim of this mini review is to summarize the evidence regarding effects of nuts on physical health, fitness, and exercise performance. Almond supplementation improves exercise performance, but pistachio supplementation does not. The effect of nuts on exercise performance was controversial. On the other hand, unsaturated fatty acid-enriched nuts had a beneficial effect on skeletal muscle mass and oxygen consumption. A diet enriched with nuts also improved physical fitness, which was enhanced by exercise. Although the characteristics of the study participants and the interventions used in the studies are heterogeneous, nuts have a potential to improve physical fitness. However, further studies are required to reveal the effects of nuts on physical fitness, exercise performance, and endurance capacity.

Keywords: nuts; exercise; unsaturated fatty acid; physical fitness; skeletal muscle

1. Introduction

Nuts are rich in proteins, fats, particularly unsaturated fatty acids, fiber, vitamins, minerals, phytosterols, and polyphenols [1]. The nut food group includes almonds, hazelnuts, walnuts, pistachios, cashews, pecans, pine nuts, macadamia nuts, Brazil nuts, and peanuts. Today, many people around the world consume nuts daily. Previous studies analyzing the data from the National Health and Nutrition Examination Survey have revealed that nut consumers had better nutrient intake than non-nut consumers [2,3]. After the early 1990s, a large number of studies on nuts and health benefits have been conducted. Clinical trials have demonstrated that nut intake improves lipid profiles [4], and epidemiological studies have shown that nut consumption is associated with a reduced risk of coronary heart disease [5]. Growing evidence suggests that nut consumption has beneficial effects on blood pressure, obesity, inflammation, and oxidative stress, which reduce the risk of cardiovascular disease (CVD) [6]. In 2013, a randomized controlled trial (RCT) showed that a Mediterranean diet enriched with mixed nuts reduced the incidence of cardiovascular events [7]. The Prevención con Dieta Mediterránea (PREDIMED) trial is a large, parallel-group, multicenter RCT conducted in Spain. This trial aimed to investigate the effects of dietary intervention alone on primary cardiovascular prevention, and one of three diet groups was given a Mediterranean diet supplemented with 30 g of mixed nuts (15 g of walnuts, 7.5 g of hazelnuts, and 7.5 g of almonds) [7]. Secondary analyses of this trial also showed that eating the Mediterranean diet enriched with mixed nuts was associated with improved abdominal adiposity [8], high-density lipoprotein function [9], and inflammation [10]. The beneficial effects of nuts on health, especially CVD, have become increasingly clear. On the other hand, evidence regarding nut consumption and physical fitness is limited. Fat supplements, including conjugated linoleic acid (CLA) and fish oil, which contains omega-3 fatty acids such as eicosapentaenoic acid (EPA) and docosahexaenoic acid (DHA), improve endurance capacity and reduce muscle damage and inflammatory responses during exercise [11]. Moreover, omega-3 fatty acid supplementation can influence skeletal muscle metabolism and has the potential to prevent sarcopenia [12]. Nuts are rich in monounsaturated fatty acids (MUFAs) (oleic acid) and polyunsaturated fatty acids (PUFAs) (linoleic and α-linoleic acid) [13,14]. The fatty acid composition of nuts is expected to be beneficial for physical fitness. Hence, the aim of this review is to summarize and evaluate the evidence related to nuts for exercise performance, endurance capacity, and skeletal muscle in addition to pathological conditions including CVD, and to discuss the potential health benefits of nuts.

2. Materials and Method

The relevant studies were identified by searching the following electronic databases: PubMed/MEDLINE and the Cochrane Library. First, to summarize the effects of nut consumption on obesity, metabolic diseases, and CVD, the relevant systematic reviews and meta-analyses were identified. Second, the studies investigating the role of nuts in exercise performance and skeletal muscle metabolism were searched. The search terms were “nuts”, “exercise”, and “skeletal muscle”. We also searched the literature using the search terms “unsaturated fatty acid”, “exercise”, and “skeletal muscle”. Inclusion criteria for study selection were as follows: (1) human studies; (2) dietary interventions (nuts, a diet enriched with nuts, or unsaturated fatty acids contained in nuts); (3) RCT or randomized crossover trials. Studies investigating the effects of nuts on body composition alone were excluded. Studies using an energy restricted diet were also excluded. The titles and abstracts of the identified articles were reviewed to determine their relevance. In total, 5 studies met the criteria.

3. Nuts for Health

3.1. Composition of nuts

We provide general information on composition of nuts, and summarize the current literature regarding beneficial effects of nuts on pathological conditions such as obesity, metabolic diseases, CVD, and liver disease. The high content of MUFAs in macadamia nuts [15], peanuts [16], and pecans [17] improves serum lipid profiles. Walnuts, which are unique because of their high content of PUFAs compared with other nuts, are also known to reduce total cholesterol and low-density lipoprotein (LDL) cholesterol levels [18,19]. Dietary PUFAs from walnuts improve insulin sensitivity in patients with type 2 diabetes [20]. Accumulating evidence suggests that the fatty acid compositions of nuts have beneficial effects on CVD risk factors. Table 1 shows the average energy, protein, fat, fiber, and fatty acid compositions of nuts [5,6].

Table 1. Compositions of nuts (per 100 g).

Nuts	*Energy (kcal)*	*Protein (g)*	*Fiber (g)*	*Fat (g)*	*SFA (g)*	*MUFA (g)*	*PUFA (g)*
Almonds	577.9	21.3	8.8	50.6	3.9	32.2	12.2
Brazil nuts	655.6	14.3	8.5	66.4	15.1	24.5	20.6
Cashews	553.1	18.2	5.9	46.4	9.2	27.3	7.8
Hazelnuts	628.3	15.0	10.4	60.8	4.5	45.7	7.9
Macadamia nuts	718	7.9	6.0	75.8	12.1	58.9	1.5
Peanuts	530.6	25.8	8.5	49.2	6.8	24.4	15.6
Pecans	690.5	9.2	8.4	72.0	6.2	40.8	21.6
Pine nuts	673	13.7	3.7	68.4	4.9	18.8	34.1

Pistachios	557.4	20.6	9.0	44.4	5.4	23.3	13.5
Walnuts	654.4	15.2	6.4	65.2	6.1	8.9	47.2

SFA: saturated fatty acid; MUFA: monounsaturated fatty acid; PUFA: polyunsaturated fatty acid.

3.2. Effects of nuts on obesity, metabolic risk factors, CVD, and liver disease

A number of systematic reviews and meta-analyses investigating the effects of nuts on pathological conditions such as obesity, dyslipidemia, and CVD have been published. Compared with control diets, nut consumption did not increase weight, BMI, or waist circumference [21]. Among included clinical trials in this study, only one RCT reported that almond supplementation at 84 g per day significantly reduced weight, BMI, and waist circumference [21]. Almonds also have a favorable effect on lipid profile. Total cholesterol and LDL cholesterol levels were significantly decreased when the daily almond consumption was ≥45 g [22]. In addition, Del Gobbo et al. [23] showed that various tree nuts intake decreased total cholesterol (−4.7 mg/dL), triglyderides (−2.2 mg/dL), LDL cholesterol (−4.8 mg/dL), and ApoB (−3.7 mg/dL) levels. Walnuts, pistachios, macadamia nuts, hazelnuts, and almonds (28.4 g per day) had significant cholesterol-lowering effects; however, stronger effects were observed for ≥60 g of nuts per day. The authors stated that the major determinant of cholesterol-lowering effects seemed to be dose rather than type of nuts. On the other hand, walnuts which are composed largely of PUFA, especially linoleic and α-linoleic acid significantly decreased total and LDL cholesterol levels [24]. Walnuts supplementation at 10–24% of total calories decreased total and LDL cholesterol levels by 10.3 mg/dL and 9.2 mg/dL, respectively [24]. The unique fatty acid profile of walnuts may beneficially affect lipid profile. Mohammadifard et al. [25] showed that nut consumption lowered systolic blood pressure (−1.29 mmHg) in individuals without type 2 diabetes. Almonds (84 g per day), walnuts (44–58 g per day), pistachios (30 or 60 g per day) had blood pressure-lowering effects. Subgroup analysis revealed that pistachios, but not other nuts, decreased both systolic (−1.82 mmHg) and diastolic (−0.80 mmHg) blood pressure [25]. Moreover, a recent systematic review and meta-analysis has shown that higher nut consumption is associated with a reduced risk of CVD and all-cause mortality [26]. A total of 20 prospective cohort studies (n = 467,389) were analyzed. Nut consumption was associated with a lower risk of CVD mortality (risk ratio (RR) = 0.73), all-cause mortality (RR = 0.81), coronary heart disease (RR = 0.66), and coronary heart disease mortality (RR = 0.70). Four weekly nuts servings (112 g per week) were associated with risk reductions in all-cause mortality (RR = 0.81) and CVD (RR = 0.72). Five studies reported that peanuts and walnuts consumption were associated with a reduced risk of CVD and all-cause mortality [26]. These findings were summarized in Table 2. There has been conflicting evidence on whether nuts have a potential to improve liver disease such as non-alcoholic fatty liver disease (NAFLD) and non-alcoholic steatohepatitis (NASH); however, the Mediterranean diet enriched with nuts may be beneficial for the treatment of NAFLD [27]. Luo et al. [28] showed that walnuts supplementation reduced hepatic fat concentration in mice. Nuts may also improve NAFLD and NASH.

Table 2. Effects of nuts on obesity, lipid profile, blood pressure, and CVD.

Authors, year	*Study design*	*Included studies*	*Dose and type of nuts*	*Results*
Flores-Mateo et al., 2013 [21]	Systematic review and meta-analysis	Randomized crossover/parallel trials	Various (almonds, cashews, peanuts, walnuts, pecans, pistachios, hazelnuts) Effective nut supplementation: 84 g/day of almonds	Weight→, BMI→, waist circumference→
Musa-Veloso et al., 2016 [22]	Systematic review and meta-analysis	RCTs	Almonds, ≥45 g/day	Total cholesterol↓, LDL cholesterol↓
Del Gobbo et al., 2015 [23]	Systematic review and meta-analysis	Controlled trials	Various (walnuts, pistachios, macadamia, hazelnuts, almonds) ≥60 g/day	Total cholesterol↓, triglycerides↓, LDL cholesterol↓, ApoB↓
Banel et al., 2009 [24]	Systematic review and meta-analysis	Randomized crossover/parallel trials	Walnuts, 10–24% of daily energy intake	Total cholesterol↓, LDL cholesterol↓
Mohammadifard et al., 2015 [25]	Systematic review and meta-analysis	RCTs	Various (almonds, walnuts, pistachios, cashews, mixed, peanuts) Effective nut supplementation: 84 g/day of almonds 44–58 g/day of walnuts 30 or 60 g/day of pistachios	Systolic blood pressure↓ in subjects without type 2 diabetes Systolic and diastolic blood pressure↓ in subjects who were supplemented with pistachios
Mayhew et al., 2016 [26]	Systematic review and meta-analysis	Prospective cohort studies	Various (not reported in detail) 112 g/week	All-cause mortality↓, CVD mortality↓, risk of CHD↓, CHD mortality

CVD: cardiovascular disease; RCT: randomized controlled trial; BMI: body mass index; LDL: low-density lipoprotein; CHD: coronary heart disease.

3.3. Adverse effects of nut consumption

Generally, nuts are safe foods with nutritional function claims; however, excess consumption of nuts induces toxicity, weight gain [29], and allergic reactions [30].

3.4. Influence of conditions of nuts on health benefits

As mentioned above, raw nuts have beneficial effects on CVD risk factors. However, commercially available nuts are usually roasted and salted. Tey et al. [31] investigated whether roasting and salting nuts had health benefits similar to raw nuts. Both forms of hazelnuts improved lipid profile and blood pressure. Schlörmann et al. [32] also reported that nuts exhibited best quality by roasting at 120–160℃. Fatty acid composition of nuts were not influenced by roasting. In addition, a systematic review shows that roasting reduces the allergenicity of nuts [33]; therefore, roasted and lightly salted nuts are effective and safe as well as raw nuts.

4. Nuts in Exercise

4.1. Effects of nuts on exercise performance

Recently, the effects of nuts on exercise performance has been reported. Nieman and colleagues [20] investigated the effects of pistachio supplementation on exercise performance and exercise-induced inflammation, oxidative stress, and immune dysfunction. This interesting randomized crossover trial enrolled 20 male cyclists who were randomly allocated to the pistachio intervention group or the non-intervention group. One subject was excluded from the analysis because he could not complete the second cycling time trial. Subjects engaged in two 75-km cycling time trials after pistachio supplementation at 85 g per day or no supplementation for 2 weeks. Subjects recorded all food and beverage intake during the 3-day period before each cycling time trial. On the trial day, subjects consumed either 42.5 g of pistachios with water or water alone 30 minutes before starting the trial. All subjects drank 3 ml of water per kg every 15 minutes, and subjects in the pistachio intervention group consumed 42.5 g of pistachios after 1 hour of cycling. Twenty-one hours after the cycling trial was finished, blood samples were taken in a fasting state. Energy intake was 35% higher in the pistachio intervention period compared with the non-supplementation period. Unfortunately, this study did not find a beneficial effect of pistachio supplementation on exercise performance. The performance times for the 75-km cycling trial were longer for subjects receiving pistachio supplementation than those of the controls. Oxygen consumption and ventilation were also lower during the pistachio supplementation period. On the other hand, exercise-induced inflammation and oxidative stress did not change. One of the strengths of this study is that a metabolomic analysis was also performed, which showed significant interaction effects for 19 metabolomics, including raffinose, (12Z)-9,10-Dihydroxyoctadec-12-enoate, and sucrose. The unfavorable effects of pistachio supplementation on exercise performance may be associated with the crosstalk between raffinose release from the colon and increased (12Z)-9,10-Dihydroxyoctadec-12-enoate, which impairs mitochondrial function. The intensive exercise induces an increase in gut permeability and alters gut microbiota related to inflammation and immunity [34]. Although the underlying mechanism is unknown, pistachio ingestion may have a negative impact on such exercise-induced changes in intestinal function. In contrast, Yi et al. [35] reported a beneficial effect of almond consumption on endurance exercise performance. Ten male athletes were randomly assigned to consume 75 g of almonds or isocaloric cookies per day. Subjects participated in a 10-week crossover trial with a 4-week phase for each diet intervention. A baseline exercise performance test was performed prior to the intervention. An exercise training program consists of 60–200 km of road endurance cycling and 4–24 km of sprint cycling. Subjects engaged in training 5–6 days a week with an incremental increase in intensity and amount. Although the rate of perceived exertion was not different between the groups, almond consumption increased the cycling distance during the time trial by 1.7 km, whereas the isocaloric cookie consumption increased it by only 0.6 km. Almond consumption also resulted in higher carbohydrate oxidation, higher blood glucose levels, lower fat oxidation, lower free fatty acid levels, and lower oxygen consumption compared with the baseline measurements, which suggests that almonds helped the athletes to efficiently use carbohydrates as an energy source during exercise. In addition, hemoglobin levels and total antioxidant capacity were higher during almond phase than those in isocaloric cookies phase. The authors concluded that almonds may be useful for improving exercise performance.

4.2. Effects of the fatty acid composition of nuts on skeletal muscle mass and endurance capacity

Nuts are rich in oleic acid, linoleic acid, and α-linoleic acid [13,14]. The risk of coronary heart disease events and deaths was reduced by 15% and 23%, respectively, after a one g increase in α-linoleic acid consumption in men [36]. A systematic review and meta-analysis also showed that oleic acid intake was associated with a reduction in the risk all-cause mortality, cardiovascular mortality, and cardiovascular events [37]. These fatty acids enriched in nuts appear to have beneficial effects on health. However, few studies have examined the associations of oleic acid, linoleic acid, and α-linoleic acid consumption with physical fitness. Cornish et al. [38] hypothesized that α-linoleic acid may have direct anti-inflammatory effects, although the increase in EPA associated with α-linoleic acid supplementation would decrease inflammation. They investigated the effectiveness of α-linoleic acid supplementation on muscle strength and mass, as well as markers of inflammation, in older individuals who performed a resistance training program for 12 weeks. Untrained subjects over 60 years of age were recruited and randomly assigned to the α-linoleic acid supplementation (~14 g per day) group or the placebo control group. The resistance training program consisted of 13 activities for the whole body. Subjects performed 2–4 sets of 10–12 repetitions at 60–85% of their

1-repetition maximum using a periodized resistance training program involving 4 blocks. After the resistance training program progressed for 12 weeks, IL-6 concentrations were decreased by 62% in men. Resistance training effectively improved chest and leg press strength, lean body mass, muscle thickness, body fat percentage, and bone mineral content and density. Although there were no significant group, sex, or time interactions, α-linoleic acid supplementation significantly increased knee flexor muscle mass in men. On the other hand, bone mineral density improved in the placebo group, whereas no change was observed in the α-linoleic acid supplementation group. α-linoleic acid acts as a substrate for EPA and DHA. This study concluded that α-linoleic acid supplementation has a minimal effect on skeletal muscle mass because the study duration was too short to improve muscle strength and mass. In addition, the authors speculated that increased EPA concentrations due to α-linoleic acid supplementation may increase prostaglandin concentrations, which have a catabolic effect on bone in older individuals [39]. A randomized, double-blind, controlled trial compared the effects of palmitic acid intake and oleic acid intake on oxygen consumption (VO_2) (L/min) during and after exercise [40]. A total of 19 healthy young subjects were randomly allocated to a palmitic acid-enriched diet (fat, 40% of energy intake; 16.8% palmitic acid, 16.4% oleic acid) group or an oleic acid-enriched diet (fat, 40% of energy intake; 1.7% palmitic acid, 31.4% oleic acid) group. After 28 days of diet intervention, the subjects performed cycling exercises at 60% of their VO_2 peak (mL/kg/min) for 80 minutes. The rates of VO_2, carbon dioxide consumption (VCO_2), and fat oxidation were measured during exercise and 270 minutes after exercise. No group differences were observed in body composition or the VO_2 peak; however, VO_2 was higher in the oleic acid group than that in the palmitic acid group. The average post-exercise VO_2 (during 60 to 270 minutes after exercise) was approximately 10% higher than the pre-exercise VO_2 in the oleic acid group, whereas there was no change in the post-exercise VO_2 in the palmitic acid group. Oleic acid protects against palmitic acid-induced lipotoxicity by increasing mitochondrial fatty acid oxidation [41]. High intake of MUFAs from nuts may alter mitochondrial function for energy expenditure during exercise.

4.3. Effects of a diet enriched with nuts on body composition and endurance capacity

The Western diet, which is characterized by the over-consumption of sugar, salt, and saturated fat, increases the risk of coronary heart disease [42], impaired immune function [43], brain function [44], and insulin sensitivity [45]. On the other hand, a Mediterranean diet enriched with mixed nuts reduces the incidence of cardiovascular events [7]. An interesting RCT was conducted to examine the effects of a Paleolithic diet with or without aerobic exercise and resistance training in Sweden [46]. A total of 32 subjects with type 2 diabetes were randomized to a Paleolithic diet without exercise group and a Paleolithic diet with exercise group, and twenty-nine subjects completed the trial. The Paleolithic diet consisted of lean meat, fish, seafood, eggs, vegetables, fruits, berries, and nuts. Refined fats, sugars and salt were excluded. Subjects consumed 60 g of nuts per day via diet intervention. The exercise group engaged in a 12-week supervised exercise program comprising a combination of aerobic exercise and resistance training for one hour per day, three times a week. The training program was a progressive design: the first session consisted of low-intensity (70% of the maximum heart rate) aerobic exercise using a cross-trainer; the second session consisted of high-intensity (100% of the maximal workload) sprint interval training on a cycle ergometer; and the third session consisted of moderate-intensity (45–60% of the maximal workload) exercise on a cycle ergometer. After aerobic exercise, subjects performed resistance training using the whole body with 10–15 repetitions for 2–4 sets. During the study period, the intake of protein, MUFAs, and PUFAs increased in all subjects. Energy intake was higher in the exercise group (1657 kcal/day) than that in the Paleolithic diet only group (1245 kcal/day). After the intervention for 12 weeks, fat mass decreased, hemoglobin A1c (HbA1c) levels decreased, and insulin sensitivity improved in both groups; however, no significant group differences were observed. In addition, the Paleolithic diet decreased leptin and adiponectin levels. The VO_2 max increased in the Paleolithic diet with exercise group, whereas no change was observed in the Paleolithic diet without exercise group. Although lean mass was decreased in both groups, it was preserved in male subjects performing the exercise intervention. This study is noteworthy in that a Paleolithic diet enriched with nuts improves glycemic control. The reduction in HbA1c level was approximately 1% for 12 weeks, which is equal to drug treatment. Low levels of carbohydrates in a Paleolithic diet may cause this beneficial effect; however, increased intake of MUFAs may also improve glycemic control [47]. The Paleolithic diet decreased fat mass; however, lean mass did not increase even with supervised exercise. This is probably because of the characteristics of the study subjects. This study included subjects with type 2 diabetes who had an average age of 60 years and a BMI of 31 kg/m^2. Obese individuals are sedentary and physically weak, and exercise interventions cannot improve obesity without decreasing lean mass as well as fat mass in obese older adults [48]. However, this study showed that the combination of a diet enriched with nuts and exercise increased cardiorespiratory fitness and preserved lean mass in men, which suggests that such a diet is also beneficial for the improvement of physical fitness in subjects with type 2 diabetes. Table 3 summarizes the studies investigating the effects of nuts, the fatty acid composition of nuts, and diets enriched with nuts on exercise performance or physical fitness.

Table 3. Effects of nuts, the fatty acid composition of nuts, and diets enriched with nuts on physical fitness.

Authors, year	*Study design*	*Subjects*	*Intervention*	*Results*
Nieman et al., 2014 [20]	Randomized crossover trial	20 male cyclists Age: 38 ± 1.6 years Sex: all men BMI: no description (height: 181 ± 2 cm; weight: 76.8 ± 2.3 kg)	Pistachio supplementation: 85 g/day for 2 weeks	Energy intake↑, performance time for the 75-km cycling trial↓, VO_2↓, ventilation↓, post-exercise oxidative stress↑

Yi et al., 2014 [35]	Randomized controlled crossover trial	8 trained male cyclists and 2 triathletes Age: 22.3 ± 1.6 years Sex: all men BMI: no description (height: 180.6 ± 7.2 cm, weight: 74.2 ± 7.7 kg)	Almond supplementation: 75 g/day for 4 weeks of almond consumption and isocaloric cookies consumption	Cycling distance↑, hemoglobin↑, total antioxidant capacity↑, FFAs↓
Cornish et al., 2009 [38]	RCT	51 untrained subjects over 60 years of age Age: 42.5 ± 8.2 years Sex: 37 men and 31 women BMI: 30.9 ± 7.5 kg/m^2	α-linoleic acid supplementation: 14 g/day Resistance training 12 weeks	Knee flexor muscle mass↑ in men IL-6↓ in men Bone mineral density→
Børsheim et al., 2006 [40]	RCT	19 healthy, non-obese young subjects Age: 25.3 ± 0.9 years in the high oleic acid group and 27.9 ± 3.5 years in the high palmitic acid group Sex: 12 men and 7 women BMI: 22.8 ± 0.7 kg/ m^2 in the high oleic acid group and: 25.2 ± 0.8 kg/ m^2 in the high palmitic acid group	Palmitic acid-enriched diet (fat, 40% of energy intake; 16.8% palmitic acid, 16.4% oleic acid) and oleic acid-enriched diet (fat, 40% of energy intake; 1.7% palmitic acid, 31.4% oleic acid) 4 weeks	VO_2↑ in the high oleic acid group compared with that in the high palmitic acid group
Otten et al., 2014 [46]	RCT	29 patients with type 2 diabetes Age: 60 years in the Paleolithic diet group and 61 years in the Paleolithic + exercise group Sex: 19 men and 10 women BMI: 31.4 kg/m^2 in the Paleolithic diet group and 31.7 kg/m^2 in the Paleolithic + exercise group	Paleolithic diet: 60 g of nuts per day Aerobic exercise and resistance training for 12 weeks	Fat mass↓, lean mass↓ in men VO_2 max↑ in the Paleolithic diet + exercise group HbA1c↓, insulin sensitivity↑, leptin↓

hs-CRP: high-sensitivity C-reactive protein; TNF-α: tumor necrosis factor-α; FFAs: free fatty acids; IL-6: interleukin-6; HbA1c: hemoglobin A1c; VO_2: oxygen consumption.

5. Limitations

Several limitations need to be addressed. Ideally, systematic search should be performed to include all the relevant studies. However, there are currently too few studies to conduct a systematic review concerning the effect of nuts on physical fitness. We included 3 studies reporting effects of the fatty acid composition of nuts and diets enriched with nuts on physical fitness; however, these studies may not clarify the direct effect of nut consumption on physical fitness. There are only 2 intervention studies investigating the effect of nuts itself in humans. It is inconclusive whether nut consumption have a beneficial effect on physical fitness. The current evidence regarding nuts for physical fitness is sparse, and further studies would be required.

6. Conclusions

It is beyond question that nuts have health benefits. Diet therapy is essential for all types of disease. Recent evidence showing that nuts reduce CVD risks [6] has a great impact on nutritional medicine. However, the effects of nuts on physical fitness in humans have not been fully investigated, and the evidence from well-designed clinical studies is limited. In this review, we summarized the relevant studies in detail. It is notable that the intake of oleic acid may increase VO_2 without exercise intervention in healthy individuals. If exercise is adequately combined with nut supplementation, skeletal muscle mass and strength will increase, and cardiorespiratory fitness will improve more effectively. On the other hand, the effects of nuts on exercise performance are controversial. A possible explanation for the discrepancy between the study results from Nieman et al. [20] and Yi et al. [35] involves the difference in the physical fitness of the subjects at baseline. A small number of subjects and a short study duration may also affect the results. In addition, the effects of nuts on exercise performance have been investigated in only young athletes. Nuts may improve physical performance as well as body composition in older individuals; however, no such reports exist. There is considerable heterogeneity between studies; the characteristics of the study participants, the amount of nut supplementation, and the study duration could affect the results. EPA, DHA, and CLA reduce muscle glycogen breakdown, muscle damage, and inflammation and may increase testosterone synthesis, which induces physical performance improvement [11]. Intake of omega-3 PUFAs was suggested to have a positive association with skeletal muscle fitness [12,49] and a beneficial effect on the exercise performance of athletes via attenuating the inflammatory and immunomodulatory response to exercise [50]. More than 20 years ago, Aguilanio and colleagues [51] reported that PUFA supplementation ameliorated exercise-induced hypoxemia. These findings suggest that unsaturated fatty acids play a pivotal role in the improvement of physical fitness. To elucidate the effect of nuts on physical performance, further studies are required. A Mediterranean diet enriched with nuts enhances antioxidant activities in individuals with metabolic syndrome [52]. Experimental studies have also shown that nuts increase hepatic antioxidant enzyme activities [53], protect against cell death and calcium dysregulation in hippocampal cells [54], improve cognitive and motor function [55], exhibit prebiotic effects [56] and even inhibit colorectal cancer growth [57]. Nuts are promising as a food with nutritional function claims.

Conflict of Interest

The authors declare no conflict of interest.

References

1. Ros E (2010) Health benefits of nut consumption. *Nutrients* 2: 652-682.
2. O'Neil CE, Keast DR, Fulgoni VL III, et al. (2010) Tree nut consumption improves nutrient intake and diet quality in US adults: an analysis of National Health and Nutrition Examination Survey (NHANES) 1999-2004. *Asia Pac J Clin Nutr* 19: 142-150.
3. O'Neil CE, Nicklas TA, Fulgoni VL III (2015) Tree nut consumption is associated with better nutrient adequacy and diet quality in adults: National Health and Nutrition Examination Survey 2005-2010. *Nutrients* 7: 595-607.
4. Mukuddem-Petersen J, Oosthuizen W, Jerling JC (2005) A systematic review of the effects of nuts on blood lipid profiles in humans. *J Nutr* 135: 2082-2089.
5. Ros E, Mataix J (2006) Fatty acid composition of nuts--implications for cardiovascular health. *Br J Nutr* 96: S29-S35.
6. Ros E (2015) Nuts and CVD. *Br J Nutr* 113: S111-S120.
7. Estruch R, Ros E, Salas-Salvadó J, et al; PREDIMED Study Investigators. (2013) Primary prevention of cardiovascular disease with a Mediterranean diet. *N Engl J Med* 368: 1279-1290.
8. Estruch R, Martínez-González MA, Corella D, et al; PREDIMED Study Investigators. (2016) Effect of a high-fat Mediterranean diet on bodyweight and waist circumference: a prespecified secondary outcomes analysis of the PREDIMED randomised controlled trial. *Lancet Diabetes Endocrinol* 4: 666-676.
9. Hernáez Á, Castañer O, Elosua R, et al. (2017) Mediterranean Diet Improves High-Density Lipoprotein Function in High-Cardiovascular-Risk Individuals: A Randomized Controlled Trial. *Circulation* 135: 633-643.
10. Casas R, Sacanella E, Urpí-Sardà M, et al. (2016) Long-Term Immunomodulatory Effects of a Mediterranean Diet in Adults at High Risk of Cardiovascular Disease in the PREvención con DIeta MEDiterránea (PREDIMED) Randomized Controlled Trial. *J Nutr* 146: 1684-1693.
11. Macaluso F, Barone R, Catanese P, et al. (2013) Do fat supplements increase physical performance? *Nutrients* 5: 509-524.
12. Jeromson S, Gallagher IJ, Galloway SD, et al. (2015) Omega-3 Fatty Acids and Skeletal Muscle Health. *Mar Drugs* 13: 6977-7004.

13. Maguire LS, O'Sullivan SM, Galvin K, et al. (2004) Fatty acid profile, tocopherol, squalene and phytosterol content of walnuts, almonds, peanuts, hazelnuts and the macadamia nut. *Int J Food Sci Nutr* 55: 171-178.
14. Ryan E, Galvin K, O'Connor TP, et al. (2006) Fatty acid profile, tocopherol, squalene and phytosterol content of brazil, pecan, pine, pistachio and cashew nuts. *Int J Food Sci Nutr* 57: 219-228.
15. Curb JD, Wergowske G, Dobbs JC, et al. (2000) Serum lipid effects of a high-monounsaturated fat diet based on macadamia nuts. *Arch Intern Med* 160: 1154-1158.
16. O'Byrne DJ, Knauft DA, Shireman RB (1997)nLow fat-monounsaturated rich diets containing high-oleic peanuts improve serum lipoprotein profiles. Lipids 32: 687-695.
17. Rajaram S, Burke K, Connell B, et al. (2001) A monounsaturated fatty acid-rich pecan-enriched diet favorably alters the serum lipid profile of healthy men and women. *J Nutr* 131: 2275-2279.
18. Sabaté J, Fraser GE, Burke K, et al. (1993) Effects of walnuts on serum lipid levels and blood pressure in normal men. *N Engl J Med* 328: 603-607.
19. Zambón D, Sabaté J, Muñoz S, et al. (2000) Substituting walnuts for monounsaturated fat improves the serum lipid profile of hypercholesterolemic men and women. A randomized crossover trial. *Ann Intern Med* 132: 538-546.
20. Nieman DC, Scherr J, Luo B, et al. (2014) Influence of pistachios on performance and exercise-induced inflammation, oxidative stress, immune dysfunction, and metabolite shifts in cyclists: a randomized, crossover trial. *PLoS One* 9: e113725.
21. Flores-Mateo G, Rojas-Rueda D, Basora J, et al. (2013) Nut intake and adiposity: meta-analysis of clinical trials. *Am J Clin Nutr* 97: 1346-1355.
22. Musa-Veloso K, Paulionis L, Poon T, et al. (2016) The effects of almond consumption on fasting blood lipid levels: a systematic review and meta-analysis of randomised controlled trials. *J Nutr Sci* 5: e34.
23. Del Gobbo LC, Falk MC, Feldman R, et al. (2015) Effects of tree nuts on blood lipids, apolipoproteins, and blood pressure: systematic review, meta-analysis, and dose-response of 61 controlled intervention trials. *Am J Clin Nutr* 102: 1347-1356.
24. Banel DK, Hu FB (2009) Effects of walnut consumption on blood lipids and other cardiovascular risk factors: a meta-analysis and systematic review. *Am J Clin Nutr* 90: 56-63.
25. Mohammadifard N, Salehi-Abargouei A, Salas-Salvadó J, et al. (2015) The effect of tree nut, peanut, and soy nut consumption on blood pressure: a systematic review and meta-analysis of randomized controlled clinical trials. *Am J Clin Nutr* 101: 966-982.
26. Mayhew AJ, de Souza RJ, Meyre D, et al. (2016) A systematic review and meta-analysis of nut consumption and incident risk of CVD and all-cause mortality. *Br J Nutr* 115: 212-225.
27. Zelber-Sagi S, Salomone F, Mlynarsky L (2017) The Mediterranean dietary pattern as the diet of choice for non-alcoholic fatty liver disease: Evidence and plausible mechanisms. *Liver Int* 37: 936-949.

28. Luo T, Miranda-Garcia O, Adamson A, et al. (2016) Consumption of Walnuts in Combination with Other Whole Foods Produces Physiologic, Metabolic, and Gene Expression Changes in Obese C57BL/6J High-Fat-Fed Male Mice. *J Nutr* 146: 1641-1650.
29. Mazokopakis EE, Liontiris MI (2017) Commentary: Health Concerns of Brazil Nut Consumption. *J Altern Complement Med* in press.
30. Stiefel G, Anagnostou K, Boyle RJ, et al. (2017) BSACI guideline for the diagnosis and management of peanut and tree nut allergy. *Clin Exp Allergy* 47: 719-739.
31. Tey SL, Robinson T, Gray AR, et al. (2017) Do dry roasting, lightly salting nuts affect their cardioprotective properties and acceptability? *Eur J Nutr* 56: 1025-1036.
32. Schlörmann W, Birringer M, Böhm V, et al. (2015) Influence of roasting conditions on health-related compounds in different nuts. *Food Chem* 180: 77-85.
33. Masthoff LJ, Hoff R, Verhoeckx KC, et al. (2013) A systematic review of the effect of thermal processing on the allergenicity of tree nuts. *Allergy* 68: 983-993.
34. Hamasaki H (2017) Exercise and gut microbiota: clinical implications for the feasibility of Tai Chi. *J Integr Med* 15: 270-281.
35. Yi M, Fu J, Zhou L, et al. (2014) The effect of almond consumption on elements of endurance exercise performance in trained athletes. *J Int Soc Sports Nutr* 11: 18.
36. Vedtofte MS, Jakobsen MU, Lauritzen L, et al. (2014) Association between the intake of α-linolenic acid and the risk of CHD. *Br J Nutr* 112: 735-743.
37. Schwingshackl L, Hoffmann G (2014) Monounsaturated fatty acids, olive oil and health status: a systematic review and meta-analysis of cohort studies. *Lipids Health Dis* 13: 154.
38. Cornish SM, Chilibeck PD (2009) Alpha-linolenic acid supplementation and resistance training in older adults. *Appl Physiol Nutr Metab* 34: 49-59.
39. Poulsen RC, Kruger MC (2006) Detrimental effect of eicosapentaenoic acid supplementation on bone following ovariectomy in rats. *Prostaglandins Leukot Essent Fatty Acids* 75: 419-427.
40. Børsheim E, Kien CL, Pearl WM (2006) Differential effects of dietary intake of palmitic acid and oleic acid on oxygen consumption during and after exercise. *Metabolism* 55: 1215-1221.
41. Henique C, Mansouri A, Fumey G, et al. (2010) Increased mitochondrial fatty acid oxidation is sufficient to protect skeletal muscle cells from palmitate-induced apoptosis. *J Biol Chem* 285: 36818-3627.
42. Mente A, de Koning L, Shannon HS, et al. (2009) A systematic review of the evidence supporting a causal link between dietary factors and coronary heart disease. *Arch Intern Med* 169: 659-669.
43. Myles IA (2014) Fast food fever: reviewing the impacts of the Western diet on immunity. *Nutr J* 13: 61.
44. Francis H, Stevenson R (2013) The longer-term impacts of Western diet on human cognition and the brain. *Appetite* 63: 119-128.
45. Deer J, Koska J, Ozias M, et al. (2015) Dietary models of insulin resistance. *Metabolism* 64: 163-171.

46. Otten J, Stomby A, Waling M, et al. (2017) Benefits of a Paleolithic diet with and without supervised exercise on fat mass, insulin sensitivity, and glycemic control: a randomized controlled trial in individuals with type 2 diabetes. *Diabetes Metab Res Rev* 33.
47. O'Keefe JH, Gheewala NM, O'Keefe JO (2008) Dietary strategies for improving post-prandial glucose, lipids, inflammation, and cardiovascular health. *J Am Coll Cardiol* 51: 249-255.
48. Villareal DT, Aguirre L, Gurney AB, et al. (2017) Aerobic or Resistance Exercise, or Both, in Dieting Obese Older Adults. *N Engl J Med* 376: 1943-1955.
49. Welch AA, MacGrego AJ, Minihane AM, et al. (2014) Dietary fat and fatty acid profile are associated with indices of skeletal muscle mass in women aged 18-79 years. *J Nutr* 144: 327-334.
50. Mickleborough TD (2013) Omega-3 polyunsaturated fatty acids in physical performance optimization. *Int J Sport Nutr Exerc Metab* 23: 83-96.
51. Aguilaniu B, Flore P, Perrault H, et al. (1995) Exercise-induced hypoxaemia in master athletes: effects of a polyunsaturated fatty acid diet. *Eur J Appl Phytsiol Occup Physiol* 72: 44-50.
52. Sureda A, Bibiloni MD, Martorell M, et al; PREDIMED Study Investigators. (2016) Mediterranean diets supplemented with virgin olive oil and nuts enhance plasmatic antioxidant capabilities and decrease xanthine oxidase activity in people with metabolic syndrome: The PREDIMED study. *Mol Nutr Food Res* 60: 2654-2664.
53. Domínguez-Avila JA, Alvarez-Parrilla E, López-Díaz JA, et al. (2015) The pecan nut (Carya illinoinensis) and its oil and polyphenolic fractions differentially modulate lipid metabolism and the antioxidant enzyme activities in rats fed high-fat diets. *Food Chem* 168: 529-537.
54. Carey AN, Fisher DR, Joseph JA, et al. (2013) The ability of walnut extract and fatty acids to protect against the deleterious effects of oxidative stress and inflammation in hippocampal cells. *Nutr Neurosci* 16: 13-20.
55. Willis LM, Shukitt-Hale B, Cheng V, et al. (2009) Dose-dependent effects of walnuts on motor and cognitive function in aged rats. *Br J Nutr* 101: 1140-1144.
56. Liu Z, Wang W, Huang G, et al. (2016) In vitro and in vivo evaluation of the prebiotic effect of raw and roasted almonds (Prunus amygdalus). *J Sci Food Agric* 96: 1836-1843.
57. Nagel JM, Brinkoetter M, Magkos F, et al. (2012) Dietary walnuts inhibit colorectal cancer growth in mice by suppressing angiogenesis. *Nutrition* 28: 67-75.