Physiology in Medicine: update on lifestyle determinants of postprandial triacylglycerolemia with emphasis on the Mediterranean lifestyle

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Maraki MI, Sidossis LS. Update on lifestyle determinants of postprandial triacylglycerolemia with emphasis on the Mediterranean lifestyle. Am J Physiol Endocrinol Metab 309: E440–E449, 2015. First published July 7, 2015; doi:10.1152/ajpendo.00245.2015.—This review updates the effect of lifestyle on plasma triacylglycerols (TAG) in the postprandial state, commonly reported as postprandial lipemia (PPL), an independent risk factor for cardiovascular diseases (CVD). Numerous studies have shown that Mediterranean diet may reduce PPL. However, most of these studies were focused on the type of fat (i.e., monounsaturated fat from olive oil), and the other components of the Mediterranean lifestyle were neglected. Physical activity, an integral part of this lifestyle, is widely investigated on its own and shown to reduce PPL. In addition, preliminary results of studies examining other Mediterranean “ingredients”, such as legumes, fish, and herbs, showed additional benefits; however, data on the long-term effects are limited. More studies are needed to confirm short-term results and investigate the effects of the whole Mediterranean lifestyle on PPL and whether these effects mediate its protective role on CVD. Moreover, investigation of the effects in nonhealthy populations and the underlying mechanisms would be clinically helpful in individualizing the appropriate intervention.

FREE-LIVING HUMANS spend most of their time in a nonfasting, postprandial state; however, routine health screening is performed in the fasting state. Regarding lipids [mainly triacylglycerols (TAG) and their carriers, TAG-rich lipoproteins (TRL)], the most profound changes are taking place in the postprandial state, i.e., the hours after the consumption of dietary fat. TAG and TRL metabolism in the postprandial state are schematically shown in Fig. 1.

Recent evidence suggests that elevated levels of plasma TAG in the postprandial state, commonly reported as postprandial lipemia (PPL) or nonfasting TAG, is associated with increased risk for atherosclerosis, independently of other known cardiovascular disease (CVD) risk factors (32, 61). In addition, TAG-TRL remnants [i.e., chylomicrons and VLDL with reduced amount or depleted of TAG after the action of lipoprotein lipase (LPL)] may penetrate the arterial wall and may be taken up by monocytes, forming foam cells. Several epidemiological studies have shown that CVD patients have increased levels of postprandial TRL (62), while VLDL remnants have also been found in atheromatous plaques. In addition, reduced TRL catabolism is associated with changes in the size of other lipoproteins (e.g., formation of HDL₃ and LDL₃; Fig. 2) that are thought to be atherogenic (66, 74), as well as oxidative stress, endothelium dysfunction, and inflammation (40, 87), thereby increasing CVD risk. Recent detailed reviews have highlighted the clinical importance of PPL (12, 37). Therefore, interventions that improve postprandial TAG and TRL metabolism may be valuable in reducing the risk of CVD.

Numerous epidemiological studies have shown that the Mediterranean lifestyle is associated with lower risk for several diseases, including CVD, and these results are also confirmed from interventional studies, such as the PREDIMED study (25) and others, as recently meta-analyzed and reviewed (25, 36). The cardioprotective effect of this lifestyle may be mediated through favorable effects on several CVD risk factors such as insulin sensitivity and fasting TAG levels (78). Whether improvements in postprandial TAG metabolism also mediate the protective role of the Mediterranean lifestyle on CVD is currently unknown.

The Mediterranean lifestyle is commonly depicted and summarized in the Mediterranean diet pyramid (Fig. 3 and Ref. 5). Although it has no particular definition, the main characteristics of the Mediterranean diet include high consumption of plant-based foods, such as olive oil and olives (as the prevalent fat), vegetables, fruits, legumes, whole-grain products, and nuts, moderate wine consumption with meals, and low consumption of red meat and meat products. The result is an increased intake of carbohydrates (~50% of energy), mainly nonrefined; fat (35–40%), mainly monounsaturated fatty acids (MUFA), and polyphenolics; moderate intake of alcohol; and low intake of saturated fatty
acids (SFA). Other important, often neglected, characteristics of the Mediterranean lifestyle include regular physical activity, adequate rest (enough sleep duration and naps), use of herbs and spices, regular (weekly) consumption of fish, and regular (daily) consumption of milk products (mainly cheese and yogurt).

Epidemiological studies investigating the association between Mediterranean lifestyle and PPL are scarce and focus only on the main characteristic of Mediterranean diet, i.e., the amount and type of fat, and not on the whole lifestyle pattern. In more detail, one study (89) found that Southern European males [consuming more percentage (%) of energy as total fat and MUFA and less polyunsaturated fatty acids (PUFA)], compared with Northern counterparts, presented differences in postprandial responses after consumption of a high-MUFA or high-SFA meal. Southern Europeans experienced an early postprandial TAG rise and a rapid return late postprandially, accompanied by decreased apolipoprotein (apo)B-48 concentrations, reflecting decreased chylomicron formation or increased clearance. On the other hand, another study found no difference between Spanish (consuming more % energy as MUFA) and Dutch subjects in daylong self-measured TAGs (86). However, it should be noted that the differences between Spanish and Dutch subjects in MUFA intake, while statistically significant, were quite small (4–7 g/day, or 3–3.5%).

Several interventional studies aimed to investigate the effect of the Mediterranean diet on PPL. However, as for epidemiological studies, no intervention study to date has investigated the effect of the Mediterranean lifestyle as a whole. Therefore, the purpose of this paper is to review the effects of the Mediterranean lifestyle “ingredients” and, where possible, of their combinations on PPL. Studies for this review were retrieved via advanced PubMed search. Search terms used included the following: “Mediterranean”, “olive”, “monounsaturated”, “nut”, “legume”, “fibre” or “fiber”, “polyphenol”, “fish”, “n-3”, “omega-3”, “exercise” or “physical activity”, “sleep” or “nap” combined with “postprandial” or “nonfasting”, and “lipemia” or “lipaemia”, or “triglyceride” or “triacylglycerol”.

The search was restricted to articles published in English. The reference lists of retrieved articles and other relevant published reviews were also reviewed. Where available data exist, the underlying mechanisms are also discussed, in order for physicians and researchers to focus on the most relevant interventions. Because of space limitations, we cannot cite the vast number of papers that contributed to this review and focus mainly on recent or the most important studies.
**Amount and Type of Fat**

*Acute effects.* A typical Mediterranean meal contains enough fat (i.e., >30 g) to induce PPL. However, the degree of PPL depends on the type of fat ingested. Compared with butter (high in SFA), olive oil (high in MUFA) produced similar (6, 38, 60, 81) or greater (38, 56) or lower (42, 43, 82) PPL in healthy populations. Mixed results were also found when comparing olive oil with other fats and oils rich in SFA (palm oil or palm olein oil or cocoa butter), or PUFA (walnuts, corn oil, salmon oil, flaxseed oil, safflower oil, or sunflower oil), or MUFA (rapeseed oil or high oleic sunflower oil).

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**Fig. 2.** Atherogenic changes induced by the accumulation of TRL. Elevated levels of TRL, i.e., chylomicron (CM), VLDL, and their remnants (CMr and VLDLr; i.e., chylomicrons and VLDL with reduced amount or depleted of TAG after the action of LPL), lead to the formation of cholesterol ester (CE)-enriched small dense LDL (LDL\(_s\)) and HDL (HDL\(_s\)). LDL\(_s\) are the more atherogenic forms of LDL due to increased binding affinity to the artery wall, whereas HDL\(_s\) are more easily catabolized, thereby decreasing HDL cholesterol. CETP, cholesterol ester transfer protein.

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**Fig. 3.** The Mediterranean diet pyramid. Reproduced from Ref. 5, which recommends use of this image without restriction.
It seems that subjects’ characteristics may influence the relationship between fat type and PPL. Higher-weight subjects benefit more from the consumption of MUFA (olive oil) rather than PUFA (walnut) or SFA (butter) (45). Also, olive oil reduced PPL in men with fasting hypertriglyceridemia (42) and in overweight subjects with type 2 diabetes (83). Increases in postprandial insulin sensitivity after MUFA intake may increase LPL activity and therefore TAG clearance. Alternatively, or additionally, TRL particles after MUFA intake may have greater affinity to hepatic receptors that are responsible for TRL remnant clearance.

Lipid bioaccessibility may affect PPL. This fact is clinically important and should be taken into account when translating research evidence into practice. A recent study showed that whole almond seeds produced 70% lower PPL than almond oil with defatted almond flour (given to provide the same nutrients) (9). Whether olives per se affect PPL differently than olive oil is currently unknown, and this issue is of great importance since the “original” Mediterranean diet includes mainly olives rather than their product. Interestingly, it has been recently revealed that pomace oil (i.e., the oil obtained by chemical processes from residues of the extraction of virgin olive oil, containing a number of unsaponifiable components from the olive skin) facilitates greater TAG clearance from TRL compared with olive oil by increasing their particle size (16, 17). Nevertheless, whether olive oil is of low or high phenolic compounds does not seem to influence PPL responses, at least in those with hypercholesterolemia (72).

Long-term effects. Several studies have compared the effects on PPL of a diet high in total fat and MUFA (HFMUFA) (olive oil) vs. low in fat and high in carbohydrates (LFHC) and/or vs. a diet high in fat and SFA (HFSFA) (butter). Many (21, 24, 33, 34, 39, 46, 68, 69, 76, 79, 90), but not all (4, 14, 20, 26, 65, 70, 71, 85), found that the HFMUFA diet was superior to the other two diets in several aspects of postprandial TAG metabolism in both healthy and unhealthy volunteers (Tables 1 and 2).

Collectively, data from these studies suggest that a HF-MUFA diet leads to significantly higher earlier (1–3 h) (24, 34, 68, 69) but lower later (>4 h) postprandial total TAG and TRL-TAG responses (21, 24, 33, 34, 68, 69). A reduced number of TRL (21, 46, 68, 76), increased production of TRL containing apoE (90) and increased size of TRL (68) (mainly chylomicrons) postprandially (note: larger chylomicrons have greater affinity to LPL and thereby cleared more efficiently) results in increased TRL catabolic rate (90) and, most importantly, increased percentage of TRL that are cleared rather than being converted to the atherogenic particles LDL (90).

Both normal and overweight subjects experienced similar reduction in PPL after a MUFA-rich Mediterranean-type diet (21). The same was true for subjects with normal or high fasting TAG levels; i.e., a MUFA-rich Mediterranean-type diet is an effective strategy to reduce an important CVD risk factor independently of body mass index or fasting TAG levels. Advantages of a HFMUFA diet have also been found in subjects with metabolic syndrome (34) or type 2 diabetes (46, 69). Of two studies performed in type 1 diabetics, the first (26) found that 4 wk on a HFMUFA diet increased PPL. However, a more recent study with a more prolonged intervention (6 mo) showed that 24-h TAG was lower after a HFMUFA than with a LFHC diet (79).

Nevertheless, as mentioned above, some studies found higher or similar PPL after a HFMUFA vs. a LFHC diet. Small sample size, no washout period, only small differences (∼3%) between diets in MUFA, higher fiber content in LFHC, or short postprandial time may account for the results of these studies. More importantly, in some of these studies, test meal composition was according to diet composition, and the LFHC meal had less (14, 20), or no (65) fat compared with the HFMUFA meal; therefore, this effect was expected, since meal total fat amount is the main determinant of PPL (14, 20, 65). However, other studies found benefits of a HFMUFA vs. a LFHC diet, even if the test meal was according to diet composition and therefore of greater fat (24, 33, 68, 79).

Legumes, Grains, and Other High-Fiber Foods

One of the main characteristics of the Mediterranean diet is the increased consumption of whole-grain products, i.e., products from grains that contain the germ, endosperm, and bran, in contrast to refined grains, which retain only the endosperm (Fig. 3 and Ref. 5). A 12-wk whole-grain cereal-based diet, compared with one using refined cereals, reduced PPL and postprandial insulin levels in subjects with metabolic syndrome without differences in postprandial apoB-48 or apoB-100 responses (27).

The Mediterranean diet includes frequent consumption of legumes such as beans, lentils, fava, peas, etc.; however, little is known about their effects on PPL. An early study showed that fiber from beans added to a low-fat meal (23 g of fat) did not affect postprandial TAG, even though it increased postprandial apoB-48 levels in healthy men (13). On the other hand, a recent study in overweight/obese type 2 diabetics showed that 275 g of almonga, but not Curruchilla, beans (Spanish types of beans) lowered postprandial TAG concentrations compared with bread (64). The difference between these two types of beans on PPL may be mediated through differences in their antinutritional content, indicating the diversity in health effects of even the same legume. Moreover, the addition of pea fiber (∼7 g more fiber in each of three main meals) for 2 days reduced postprandial TAG concentrations during breakfast and lunch the second day in healthy males (73). Carob is used in Mediterranean countries such as Cyprus, Malta, and Greece as a snack or cocoa substitute. Interestingly, carob pulp added to a low-fat meal decreased PPL in a dose-response manner (28). However, more studies are needed to evaluate the long-term effects of legumes on PPL and the underlying mechanisms.

Other Characteristics of the Mediterranean Diet

Dairy products. A recent study in healthy males found that increased calcium intake from dairy products (milk and yogurt) reduced PPL in a single high-fat meal, presumably due to reduced fat absorption, whereas supplementary calcium carbonate did not exert such an effect (44). Recent studies showed that a meal supplemented with whey protein lowers PPL compared with cod or gluten meal in both obese nondiabetics (30) and type 2 diabetics (57) due to lower TAG in chylomicrons. Additionally, in obese nondiabetics, whey protein supplementation for 12 wk decreased the postprandial apoB-48 responses compared with casein without affecting postprandial TAG concentrations, suggesting different short- and long-term

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Table 1. Interventional studies on the long term effect of MUFA-rich vs. other diets on PPL in a healthy population\textsuperscript{a,b}

<table>
<thead>
<tr>
<th>Subjects' Important Characteristics</th>
<th>Experimental Diet</th>
<th>Duration</th>
<th>Crossover\textsuperscript{c}</th>
<th>Test Meal\textsuperscript{d}</th>
<th>Pre &amp; Post\textsuperscript{e}</th>
<th>T\textsuperscript{f}</th>
<th>PPL Responses</th>
<th>Important Notes</th>
<th>Reference</th>
</tr>
</thead>
<tbody>
<tr>
<td>M(20) Young</td>
<td>HFMUFA (olive oil) vs. LFHC/ALA (walnuts)</td>
<td>4 wk</td>
<td>Y</td>
<td>Different bw diets (corresponding to diet composition)</td>
<td>N</td>
<td>8</td>
<td>ppTAG at 2 h HFMUFA &gt; LFHC/ALA</td>
<td>Differences in MUFA content between diets only 3 or 4.5%</td>
<td>(24)</td>
</tr>
<tr>
<td>M(20) Young</td>
<td>HFMUFA (olive oil) vs. HFSA (butternut) vs. LFHC/ALA (walnuts)</td>
<td>4 wk</td>
<td>Y</td>
<td>Different bw diets (corresponding to diet composition)</td>
<td>N</td>
<td>11</td>
<td>ppTAG &amp; ppTRL-TAG early (1-3 h): HFMUFA &gt; LFHC/ALA</td>
<td>(68)</td>
<td></td>
</tr>
<tr>
<td>M(20) Young</td>
<td>HFMUFA (olive oil) vs. MMUFA and HMUFA (manufactured fat)</td>
<td>8 wk</td>
<td>Same after all diets</td>
<td>HSFSA vs. MMUFA or MMUFA: MUFA vs. HSFSA</td>
<td>N</td>
<td>8</td>
<td>TAG AUC &amp; IAUC: ns</td>
<td>Differences in MUFA content between diets only 4.5%</td>
<td>(76)</td>
</tr>
<tr>
<td>B(25) B(26)</td>
<td>HSF vs. MMUFA, HFSA vs. HMUFA, MMUFA vs. HMUFA (manufactured fat)</td>
<td>8 wk</td>
<td>Y</td>
<td>apoB48 AUC &amp; peak: HMFUFA = MMUFA &lt; LFHC/ALA</td>
<td>N</td>
<td>9</td>
<td>Differences in diet MUFA content between diets only 4.5%</td>
<td>(70)</td>
<td></td>
</tr>
<tr>
<td>M(23)</td>
<td>HMFUFA (manufactured fat) vs. LFHC</td>
<td>8 wk</td>
<td>Y</td>
<td>Same after both diets</td>
<td>N</td>
<td>9</td>
<td>Differences in diet fiber content LFHC &gt; HMFUFA</td>
<td>(4)</td>
<td></td>
</tr>
<tr>
<td>M(23) M(24)</td>
<td>HMFUFA (olive oil) vs. LFHC</td>
<td>6–7 wk</td>
<td>N</td>
<td>HMFUFA before &amp; after both diets</td>
<td>Y</td>
<td>8</td>
<td>Pre vs. post in each diet: TAG AUC: ns</td>
<td>Differences in diet fiber content LFHC &gt; HMFUFA</td>
<td>(39)</td>
</tr>
<tr>
<td>M(19) M(18)</td>
<td>HMFUFA (olive oil) vs. LFHC</td>
<td>7 wk</td>
<td>N</td>
<td>Same standard meal before &amp; after both diets</td>
<td>Y</td>
<td>8</td>
<td>TAG AUC: pre vs. post: only in LFHC</td>
<td>Small weight loss</td>
<td>(90)</td>
</tr>
<tr>
<td>B(20)</td>
<td>HMFUFA (olive oil) vs. LFHC</td>
<td>3 wk</td>
<td>Y</td>
<td>Small frequent meals corresponding to diet composition</td>
<td>N</td>
<td>14</td>
<td>TR-LapoA, TRL fractional catabolic rate, % TRL cleared rather than converted to LDL: HMFUFA &gt; LFHC</td>
<td>Differences in diet fiber content: LFHC &gt; HMFUFA</td>
<td>(20)</td>
</tr>
</tbody>
</table>

\textsuperscript{a}For clarity, boldface studies reported significant reduction in PPL after MUFA-rich diet or/and compared with other diets, while nonboldface studies did not.\textsuperscript{b}apo, apolipoprotein; AUC, area under the concentration vs. time curve in the postprandial state; B, both sexes; bw, between; HMFUFA, high in total fat and MUFA; HFSA, high in total fat and SFA; HFSA, high in MUFA; HSFA, high in SFA; IAUC, incremental area under the concentration vs. time curve in the postprandial state; LFHC, low in fat and high in carbohydrates; LFHC/ALA, LFHC enriched in α-linolenic acid; M, men; MUFA, monounsaturated fatty acids; MMUFA, moderate in MUFA; ns, not significant (P > 0.05); NW, normal weight; OW, overweight; pp, postprandial; PPL, postprandial lipemia; SFA, saturated fatty acids; TAG, triacylglycerols; TRL, TAG-rich lipoproteins; wk, weeks.\textsuperscript{c}whether study was of crossover design; Y, Yes; N, no.\textsuperscript{d}information regarding the test meal given to investigate PPL.\textsuperscript{e}whether the test meal was given before and after each experimental diet: Y Yes, both; N, No, only after each experimental diet.\textsuperscript{f}duration of postprandial investigatin in hours.

effects of whey protein and/or each dairy product (11). Several types of cheeses consumed in the Mediterranean region include whey protein, such as ricotta in Italy, or anthotyros, manouri, and mizithra in Greece. However, the effect of these dairy products on PPL is currently unknown.

Fish. Several studies have investigated the effects of fish oil supplementation; however, little is known regarding the effect of fish intake per se on PPL. In the short term, baked herring produced higher TAG clearance than baked minced beef in overweight men (80). In the long term, a diet naturally rich in long-chain n-3 fatty acids (salmon, dentex, or anchovies) for 8 wk significantly reduced VLDL-apoB-48 and tended to decrease postprandial TRL, total TAG concentrations, and chylomicron remnants in overweight subjects (3). It should be noted that the amount and frequency of fish consumption in this study (330 g, 3 times/wk) is ordinary in the Mediterranean diet. A previous study of longer duration also found decreases in healthy males in postprandial total and chylomicron-TAG responses after 15 wk on a fish-rich diet (~4 fish-containing meals/wk) (1).
## Table 2. Intervventional studies on the long term effect of MUFA-rich vs. other diets on PPL in a nonhealthy population\(^{a,b}\)

<table>
<thead>
<tr>
<th>Subjects' Important Characteristics</th>
<th>Experimental Diet</th>
<th>Duration</th>
<th>Crossover(^{c})</th>
<th>Test Meal(^{d})</th>
<th>Pre &amp; Post(^{e})</th>
<th>T(^{f})</th>
<th>PPL Responses</th>
<th>Important Notes</th>
<th>Reference</th>
</tr>
</thead>
<tbody>
<tr>
<td>B(72) At least one CVD risk factor</td>
<td>LFHMUFA (olive oil, Mediterranean type) vs. LF-AHA</td>
<td>5 mo</td>
<td>N</td>
<td>Same continental breakfast before and after both diets</td>
<td>Y</td>
<td>5</td>
<td>Pre vs. post in each diet:</td>
<td>Very small difference in MUFA intake (1-2%), not HMU (15%), not HF</td>
<td>(21)</td>
</tr>
<tr>
<td>B(63)</td>
<td></td>
<td></td>
<td></td>
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<td></td>
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<td></td>
</tr>
<tr>
<td>M(6) MS</td>
<td>HFMUFA (manufactured fat) vs. HSFA vs. LFHC vs. LFHCn3</td>
<td>12 wk</td>
<td>N</td>
<td>Same before &amp; after all diets</td>
<td>Y</td>
<td>4</td>
<td>Pre vs. post in each diet: TAGAUC: ns</td>
<td>Too small sample size</td>
<td>(85)</td>
</tr>
<tr>
<td>B(26) MS</td>
<td>HFMUFA vs. HSFS vs. LFHC vs. LFHCn3</td>
<td>12 wk</td>
<td>N</td>
<td>Fat composition according to diet</td>
<td>Y</td>
<td>8 h</td>
<td>Pre vs. post in each diet: TAGAUC &amp; large TRL-TAG iAUC:</td>
<td>Due to main differences in fat content of test meal</td>
<td>(34)</td>
</tr>
<tr>
<td>B(32)</td>
<td></td>
<td></td>
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<td>B(28)</td>
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<tr>
<td>B(17) IR, COB, offsprings of OB, DB2</td>
<td>HFMUFA (olive oil) vs. HSFA (butter) vs. LFHC</td>
<td>4 wk</td>
<td>Y</td>
<td>Different bw diets (corresponding to diet composition)</td>
<td>N</td>
<td>3</td>
<td>TAGAUC: LFHC &lt; others</td>
<td>Due to main differences in fat content of test meal Only 3 h</td>
<td>(65)</td>
</tr>
<tr>
<td>M(11) DB2</td>
<td>HMFUFA (30 ml olive oil) vs. PUFA (30 ml sunflower oil) vs. LFHC</td>
<td>2 wk</td>
<td>Y</td>
<td>Different bw diets (corresponding to diet composition)</td>
<td>N</td>
<td>8</td>
<td>TAGAUC: ns ppChylomicron- &amp; ppVLDL-TAG: others</td>
<td>No washout period Only 2 wks</td>
<td>(46)</td>
</tr>
<tr>
<td>B(12) DB2, BMI &lt;30</td>
<td>HFMUFA (olive oil) vs. LFHC</td>
<td>6 wk</td>
<td>Y</td>
<td>Same after both diets</td>
<td>N</td>
<td>6</td>
<td>Small VLDL-TAG iAUC &amp; ppapoB48: HFMUFA earlier increase and faster clearance of pTAG and large TRL-TAG compared to HSFA and LFHC</td>
<td>No washout period Differences in diet fiber content: LFHC &gt; HFMUFA</td>
<td>(71)</td>
</tr>
<tr>
<td>M(11) OW/DB2, DB2 offsprings</td>
<td>HMUFA (olive oil) vs. HSFA (butter)</td>
<td>3 wk</td>
<td>Y</td>
<td>Same after both diets</td>
<td>N</td>
<td>6</td>
<td>Small VLDL-TAG iAUC:</td>
<td></td>
<td>(69)</td>
</tr>
<tr>
<td>B(12) OB, DB2</td>
<td>HFMUFA vs. LFHC/Hfiber</td>
<td>4 wk</td>
<td>Y</td>
<td>Different bw diets (corresponding to diet composition), before intervention same for all</td>
<td>N</td>
<td>6</td>
<td>TAGAUC: chylomicron TAG iAUC: large VLDL-TAG iAUC: LDL-TAG iAUC: self-measured TAG 3 h after lunch: HFMUFA &gt; HCHOHfiber</td>
<td>Main differences in fat content of test meal</td>
<td>(20)</td>
</tr>
<tr>
<td>B(17) OB, DB2</td>
<td>HFMUFA vs. LFHC/Hfiber</td>
<td>8 wk</td>
<td>N</td>
<td>Different bw diets (corresponding to diet composition), before intervention same for all</td>
<td>Y</td>
<td>6</td>
<td>Pre vs. post in each diet: HFMUFA: %ppTAG increase at 4&amp; 6 h HCHOHfiber: %ppTAG at 6 h: HFMUFA: HCHOHfiber &gt; HCHOHfiber</td>
<td>Main differences in fat content of test meal</td>
<td>(14)</td>
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<tr>
<td>B(20)</td>
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<tr>
<td>B(17) DB1</td>
<td>HFMUFA vs. LFHC</td>
<td>4 wk</td>
<td>Y</td>
<td>Both types (standard or same fat composition as diet)</td>
<td>N</td>
<td>10</td>
<td>ppTAG: HFMUFA &gt; LFHC</td>
<td></td>
<td>(26)</td>
</tr>
<tr>
<td>B(15) B(15) DB1</td>
<td>HFMUFA (olive oil) vs. LFHC</td>
<td>6 mo</td>
<td>N</td>
<td>Same breakfast &amp; lunch; dinner according to diet</td>
<td>Y</td>
<td>24</td>
<td>TAG AUC &amp; ppTAG: HFMUFA &lt; LFHC</td>
<td></td>
<td>(79)</td>
</tr>
</tbody>
</table>

\(^a\)For clarity, boldface studies reported significant reduction in PPL after MUFA-rich diet or/and compared to other diets, while nonboldface studies did not.\(^b\)apo, apolipoprotein; AUC, area under the concentration-vs. time curve in the postprandial state; B, both sexes; bw, between; COB, centrally obese; CVD, cardiovascular disease; DB1, type 1 diabetes; DB2, type 2 diabetes; HFMUFA, high in total fat and MUFA; HSFA, high in total fat and SFA; HFMUFA, high in MUFA; HSFA, high in SFA; I/AUC, incremental area under the concentration-vs. time curve in the postprandial state; IR, insulin resistant; LF-AHA, low fat; American Heart Association type; LFHC, low in fat and high in carbohydrates; LFHCn3, LFHC supplemented with n-3; LFHC/Hfiber, LFHC and high in fiber; LFHMUFA, low fat and high in MUFA; M, men; mo, months MS, metabolic syndrome; MUFA, monounsaturated fatty acids; ns, not significant (P > 0.05); OB, obese; OW, overweight; pp, postprandial; PPL, postprandial lipemia; PUFA, polyunsaturated fatty acids; SFA, saturated fatty acids; TAG, triacylglycerols; TRL, TAG-rich lipoproteins; wk, weeks; \(^c\)whether study was of crossover design; Y, Yes; N, no; \(^d\)information regarding the test meal given to investigate PPL; \(^e\)whether the test meal was given before and after each experimental diet: Y, Yes, both; N, No, only after each experimental diet; \(^f\)duration of postprandial investigation in hours.

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**Alcohol and wine.** Although an early study showed that acute consumption of about one or two glasses of wine along with a high-fat meal did not significantly affect PPL in healthy volunteers (22), a more recent study in dyslipidemic postmenopausal women showed that 400 ml of red wine acutely increased postprandial TAG concentrations and the incremental area under the TAG concentration-versus-time curve: apoB-48 ratio, compared with water, suggesting an increase in larger, TAG-enriched chylomicron particles (59); however, this effect was abolished when red wine was dealkoholized (59). Other studies found similar results, as reviewed (67). However, it is currently unknown whether this unfavorable effect of wine is transient or not. A recent study, investigating another alcohol drink (vodka), showed that the effect on PPL is transient and abolished ∼12 h after alcohol intake (58). Indeed, epidemiological studies indicate that low or moderate consumption of alcohol is associated with lower postprandial TAG concentrations in a white population (75, 84), and this may be one, albeit not the sole, mechanism by which low to moderate alcohol consumption is associated with reduced CVD risk (23, 31, 54).

**Other Foods High in Phenolic Compounds**

**Herbs, spices, tea, etc.** One of the main characteristics of several popular diets (Indian diet, Mediterranean diet, etc.), often neglected, is the frequent use of herbs and spices in meal preparation. A recent study in healthy, slightly overweight men (77) showed that adding 14 g of a mixed herb/spice blend (black pepper, cinnamon, cloves, garlic powder, ginger, Mediterranean oregano, paprika, rosemary, turmeric) to a moderate-fat meal (∼50 g of fat) significantly reduced PPL by 31%, presumably due to the high concentration of phenolic antioxidants in spices, which may have delayed gastric emptying and directly inhibited pancreatic lipases. On the other hand, in a previous study in overweight/obese men with type 2 diabetes (41), adding ∼12 g of a similar mix to 250 g of ground beef did not influence PPL; however, the low fat content (∼25 g) and/or medication used by the participants may have influenced the results. Nevertheless, 3 g of cinnamon does not affect PPL in healthy subjects (52) although investigated only for 3 h.

Acute coffee consumption after a meal does not influence PPL (10); neither does black tea (29). The effect of other herbal teas used in the Mediterranean diet, such as linden, flamouri, diktamo, louiza, etc., is currently unknown.

**Phenolics from fruits.** The addition of 1 liter of red orange juice (high in anthocyanin) to a high-fat meal results in a reduced increase in postprandial TAG concentrations compared with water and blond orange juice in healthy subjects (19). On the other hand, the addition of a pomegranate juice (high in anthocyanin) did not influence PPL for 4 h, albeit not the sole, mechanism by which low to moderate alcohol consumption is associated with reduced CVD risk (23, 31, 54).

**Physical activity.** It is well established that a single bout of exercise reduces PPL (50, 51), mainly by increasing TRL-TAG clearance, and to a lesser extent by reducing VLDL-TAG production (7, 8). The main moderator of this effect is exercise energy expenditure (48, 49); an energy expenditure of ∼30 kJ/kg body mass (or ∼2–2.5 MJ) is required. For resistance or high-intensity interval exercise, for those following a moderate- rather than a high-fat diet, and for those with obesity or fasting hypertriglyceridemia, a smaller energy expenditure is probably sufficient (51). Furthermore, if a prudent diet (with moderate fat intake, high in MUFA, like the Mediterranean diet) is followed, exercise may be of less load. However, since training studies have shown that the effect of exercise is transient, exercise should be included as a part of daily living, as in the Mediterranean lifestyle, and not performed only occasionally, although the effort need not be a single continuous bout but instead could be spread out throughout the day, since the benefits of intermittent compared with continuous exercise on PPL are equal or possibly even greater (2).

**Sleep habits.** Sleep habits (duration and quality) in Western-type societies have changed due to lifestyle and workload, affecting insulin sensitivity and several other CVD risk factors (18, 55). U-shaped associations between sleep duration and high fasting TAG levels were observed among women only (35), with those sleeping 6–7 h presenting the lowest levels. However, to the best of our knowledge, associations between sleep duration and/or quality and PPL have not been investigated. The only relevant data come from two interventional studies, one on the effect of short-term partial sleep deprivation on 24-h TAG levels and the other on the effect of total sleep deprivation followed by normal sleep in night shift workers. In more detail, 4 days of partial sleep deprivation (4 h sleep/night) did not affect 24-h TAG levels on the 4th day compared with normal sleep (9 h sleep/night) (63). Even though subjects in this study were under controlled isocaloric feeding, observed weight loss may have influenced the results. In the other study, although total sleep deprivation did not affect PPL immediately (during the following breakfast), PPL was increased after recovery sleep (during the breakfast the next day after recovery sleep), mainly due to increases in fasting TAG levels (88). In addition, no study to date has investigated the effect on PPL of daytime naps, a habit in the Mediterranean lifestyle. Therefore, more studies are needed to clarify the role of sleep habits on PPL.

**Conclusions**

It seems that most components of the Mediterranean lifestyle may reduce PPL, an important CVD risk factor, with the exception of wine. Although olive oil is a main component of this pattern, preliminary results of studies of several other components, such as fish, legumes, herbs, and physical activity, are very promising. More studies are needed to confirm these results, investigate long-term effects and, most importantly, investigate the lifestyle as a whole. In addition, inves-
tigation of the underlying mechanisms would increase our knowledge and may be also helpful in the clinical setting. Finally, studies are needed to investigate whether the effect of the Mediterranean lifestyle and its components on PPL mediate the overall well-established protective role of this lifestyle on CVD.

DISCLOSURES

No conflicts of interest, financial or otherwise, are declared by the author(s).

AUTHOR CONTRIBUTIONS

Author contributions: M.M. conception and design of research; M.M. analyzed data; M.M. interpreted results of experiments; M.M. drafted manuscript; M.M. and L.S.S. edited and revised manuscript; M.M. and L.S.S. approved final version of manuscript.

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