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Review

Metabolic fate of saturated and monounsaturated dietary fats: The Mediterranean diet revisited from epidemiological evidence to cellular mechanisms

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ABSTRACT

Increasing evidence indicates favourable effects of the Mediterranean diet, partly associated to its monounsaturated fatty acids (MUFA) content on both obesity and diabetes. However, neither the underlying mechanisms by which the Mediterranean diet exerts its protective effect, nor the interplay with other environmental factors (i.e. physical activity), are fully characterised. In this review, we examined recent data on how the metabolic fate of MUFA and saturated fatty acids (SFA) differs. Because of differential packaging into lipoproteins, hydrolysis of triacylglycerol-rich lipoproteins by lipoprotein lipase and transport into oxidative tissues, MUFA are oxidised more than SFA. This high MUFA oxidation favour lipid oxidation and according to the oxidative balance concept reduces the risk of obesity. It also improves the intra-muscular triacylglycerol turnover, which mitigates the SFA-induced accumulation of diacylglycerol and ceramides, and thus protects the insulin sensitivity and cell viability. Finally, physical activity through its action on the energy turnover differentially regulates the metabolism of SFA and MUFA. The putative combined role of AMP-activated kinase and mitochondrial glycerol-3-phosphate transferase on the intra-muscular partitioning of MUFA and SFA provides new areas of research to better understand the beneficial effects of the Mediterranean diet and physical activity on obesity and diabetes.

Contents

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1. Introduction

Historically, the health fame of the Mediterranean diet emerged from the Seven Countries Study [1] conducted by Ancel Keys in the 1950–1960s. He looked at differences in coronary heart disease between 16 areas in seven countries (the United States, Finland, The Netherlands, Italy, former Yugoslavia, Greece and Japan) and showed that men in the three Mediterranean areas (South Dalmatia, Italy and Crete) had similar incidence of heart diseases than in Japan but much lower than in US and Northern Europe [1,2]. This was attributed to the adherence of these Mediterranean populations to the traditional dietary pattern found in the olive tree-growing areas around the Mediterranean basin [3–5]. The diet he observed was based on an abundant consumption of plant foods (vegetables, potatoes, legumes, nuts and cereals like pasta, bread and rice), fresh fruits and fishes. Other representative features were the consumption of olive oil as the main source of fat, the moderate but consistent wine consumption with meals, relatively low amounts of meat (mainly poultry, instead of beef and pork) and low to moderate consumption of dairy products.

Over the past 40 years, the dietary patterns of the Mediterranean countries have, however, changed rapidly because of the socio-economic changes throughout Europe associated with an increased consumption of animal products and saturated fat in detriment to plant foods consumption [6]. Yet, between-populations epidemiological studies still point out lower incidence of chronic diseases in the Mediterranean countries than in the westernized countries [7]. This is likely attributable to the persistence of some main features of the diet such as the almost exclusive use of olive oil as the main added lipid and the high consumption of fruit and vegetables [8,9]. Consequently, the concept of the Mediterranean diet has continued to mobilise attention of researchers who had extensively studied the Mediterranean diet and its related health outcomes, i.e. reduced mortality, cardiovascular diseases, prevalence of metabolic syndrome and some cancers.

More recently, a growing body of data has pointed out the beneficial effects of the Mediterranean diet against overweight and obesity [10]. Interestingly, overweight, and ultimately obesity, is a serious risk factor for multiple chronic diseases, including cardiovascular disease, hypertension, diabetes, cancers, and arthritis, which incidences are clearly lowered by adoption of a Mediterranean diet [7]. As Schröder [10] reviewed it, one of the protective effects of the Mediterranean diet against obesity would be the remarkably lower average energy density than that found in Northern Europe and US. This can be explained by the large amount of vegetables, fruits, salads consumed in the Mediterranean basin, which have a relatively low energy density due to their considerable water content [11]. Moreover, vegetables are rich in fibres, which are known to be satiation and satiety factors [12,13]. On the other hand, Schröder [10] pointed out that the high content of vitamin, anti-oxidants, carotenoids, polyphenolic compounds and magnesium in the Mediterranean diet may have specifically positive effects on insulin sensitivity.

Based on this review, one may consider the protective role of the Mediterranean diet on obesity and diabetes easily understandable. However, a paradox emerges. Whereas the key role of dietary fat in the development of obesity is well accepted, it is surprising to note that the Mediterranean diet is characterized by a significant fat content ranging from moderate fat consumption in Spain (30% of daily energy intake) to high fat consumption in Greece (40% of daily energy intake) [2]. Interestingly, the Mediterranean diet is characterized by a specific fatty acids (FA) pattern. It is low in saturated fatty acids (SFA) (7–8% of energy) and high in monounsaturated fatty acids (MUFA) (higher than 20% of total energy), because the fat source consisted primarily of olive oil [14,15]. This results in a higher ratio of MUFA to SFA than in any other places of the world, including Northern Europe and North America [16,17]. This specific dietary FA pattern may explain the paradox since it exists a subtle relationship between dietary fat amount and weight regulation. Indeed in addition to the amount of fat, further evidence showed that the quality of fat is an important factor to consider in the development of overweight and obesity [18]. Some cross-sectional studies identified positive associations between the consumption of SFA and the risk for obesity and its related disorders, but negative associations for that of MUFA [19–22]. These associations are clearly not causal and the underlying mechanisms are still to be delineated. One possibility may be the differential metabolism and oxidation rate between MUFA and SFA [23], which has been associated with a differential impact on both fat oxidation [24] and body weight [25].

Finally, this hypothesis is further complicated by another parameter known to modulate fat oxidation [26], the physical activity. Interestingly, the adherence to the Mediterranean diet has been recently associated with physical activity during leisure time in both men and women [8]. Thus, instead of referring to the generic expression "Mediterranean diet", it could be more appropriate to talk about the Mediterranean lifestyle.

This review was conducted to compile recent data, and to propose hypotheses, regarding how the metabolic fates of MUFA and SFA differ. Herein, we briefly review the epidemiological data and frame this within the concept of fat balance. In addition, we compile available data on the differential digestion, assimilation, trafficking and cellular metabolism of SFA and MUFA. Despite previous reviews, such a compilation is missing from literature, because most of the reviews for the last decade have focused on other aspects of the metabolism of SFA and MUFA. Finally in light of recent data, we wish to highlight the critical interaction with physical activity and how this might alter the metabolic fate of SFA and MUFA. Although we recognize that the metabolism of a specific FA is not necessary applicable for a class of FA, data were rarely available for several FA of a same class. Therefore we decided, most of the time, to concentrate on the metabolism of oleate (18:1) and palmitate (16:0), which are the main MUFA and SFA of the human diet.