Review Article

Dietary fat and heart health: in search of the ideal fat

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Introduction

In the consideration of dietary fat and heart disease several questions arise. First, how much fat is 'healthy', both in terms of the total dietary amount and as a percentage of total dietary calories (% en), for example, 20% en, 30% en or 40% en? Second, once these fat intake parameters are ascertained, what is the proper balance of fatty acids (ratio of saturated fatty acids (SFA) to monounsaturated fatty acids (MUFA) to polyunsaturated fatty acids (PUFA)) and within each of these categories, which specific SFA and PUFA are most healthy? Third, how can one measure a 'healthy response' to changes in these dietary fat components? Fourth, what influence does dietary cholesterol have in this scenario? Finally, how important is the underlying lipoprotein profile of an individual when considering their response to fat?

The answers to these questions are complex, but it is generally agreed by most in the field that an individual's response to dietary fat can be best evaluated by measurements of total cholesterol (TC), low-density lipoprotein (LDL)-cholesterol (C) and high-density lipoprotein (HDL)-C, with the lowest TC and LDL/HDL ratios being considered ideal. Also to be considered is how fat affects the size of the LDL particle, as small, dense LDL are associated with increased coronary heart disease (CHD).

How much fat?

The current National Cholesterol Education Program (NCEP) and American Heart Association (AHA) dietary guidelines comprise the best and most relevant guide for fat and cholesterol intake. They recommend limiting fat to 30–40% en, with the prudent recommendation at the lower end of this range because 40% en, which is common in the North American diet, tends to have the undesirable consequence of raising TC and LDL-C. Decreasing fat to 20% en or less can also be troublesome because although LDL-C may decline, HDL-C may also fall, even as triglycerides tend to rise. This combination typically leads to more dense, atherogenic LDL particles. The reason for the latter adverse lipoprotein profile is probably that the balance between the SFA : MUFA : PUFA ratio is often distorted at 20% en. That is, PUFA can easily become limited, thereby distorting lipoprotein metabolism and the lipoprotein profile.

Fatty acid balance

The original AHA Step I fat recommendation was perceptive because it recognised the significance of the fatty acid balance at approximately 1:1:1 for SFA : MUFA : PUFA. Careful review of numerous reports in the literature has revealed the importance of this balance for generating the best LDL/HDL ratio. Furthermore, it would appear that the balance is critical at any level of fat intake if one wishes to avoid adversely affecting the lipoprotein profile.

Saturated and trans fatty acids

Within the concept of a 'balance' among classes of SFA, MUFA and PUFA is the issue of which specific SFA or PUFA are best. Many studies have suggested that SFA raise TC, LDL and HDL, and that PUFA lower them. But certain SFA (as consumed in our daily diet) are better than others in terms of their impact on the LDL/HDL ratio. Fats rich in 12:0 + 14:0 (e.g., milk fat, coconut oil and palm kernel oil) raise LDL the most. Stearic acid (18:0) is not very prevalent in saturated fats, but it is neutral in its effect on blood cholesterol when consumed in natural fats. The most common SFA is palmitic acid (16:0), so-named because it represents the major SFA in palm oil. The 16:0 SFA is present to some degree in essentially all fats and is by far the most prevalent SFA in our diet. Considering the influence on the lipoprotein profile, 16:0 is intermediate, that is, it can be neutral when placed on a triglyceride molecule with MUFA, PUFA or 18:0, or cholesterol-raising when attached along with 12:0 + 14:0. In high amounts, 16:0 can even raise TC and LDL when substituted for 18:0, MUFA or PUFA in people who already have elevated TC or who eat large amounts of cholesterol. Accordingly, the general advice has been to remove as much SFA from the diet as possible. But this is not practical because the manufacture of many food products requires SFA (or some facsimile thereof, such as *trans* fatty acids (TFA)), and extreme removal of dietary

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SFA is not prudent because their deletion from the diet surprisingly exerts an adverse effect on the LDL/HDL ratio. Even the 'less than 7% of calories' now proposed by NCEP and AHA can prove deleterious if total fat is allowed to drift toward 40% en. So what should be the approach to saturated fat (SAT), and what is the best dietary combination of SFA? In recent years one mistaken answer has been to utilise synthetic SFA manufactured by 'hardening' vegetable oils through hydrogenation. This process makes a stiff, plastic fat that is rich in so-called TFA. But it turns out that certain of these TFA can be worse than any of the individual natural SFA because they not only raise LDL but also lower HDL, leading to an unfortunate and exaggerated increase in the LDL/HDL ratio (unfortunate in terms of cardiovascular risk). TFA also increase a highly atherogenic lipoprotein in the LDL fraction called lipoprotein (a).

An alternative to this predicament is to provide a reasonable level of SFA in our diet by careful selection of naturally available SFA. Our research with monkeys and humans indicates that the guidelines are best tempered by the original AHA Step I diet (30% en from dietary fat and 1:1:1 for SFA : MUFA : PUFA) and that the best SFA are 16:0 and 18:0 from natural fats. This conclusion is derived from carefully analysing all aspects of the NCEP/AHA recommendations coupled with analysis of the available lipoprotein data in relevant studies involving the controlled intake of dietary fat in humans (and experimental animals).

Balance among polyunsaturated fatty acids

In selecting PUFA, the issue of whether to include linoleic acid (18:2 n-6), linolenic acid (18:3 n-3) or longer n-3 fatty acids like eicosapentanenoic acid and docosapentaenoic acid must be considered. Both n-6 and n-3 families are essential fatty acids (needed in the diet because the body cannot synthesise them) and both are important to health, especially cardiovascular health. The linoleic acid level has the greatest impact on regulating the LDL/HDL ratio, whereas linolenic acid and its longer derivatives have a major influence over the clotting mechanism, as well as stabilising the heart against abnormal beating (arrhythmia) that can lead to sudden death. Diets enriched in 18:3 n-3 or 22:6 n-3 have been shown to exert a significant anti-CHD effect in humans, both in clinical and epidemiological studies. The best dietary fat would contain an ideal balance (7:1) of n-6 linoleic to n-3 linolenic acids. This balance is not available in partially hydrogenated margarines, in which most of the n-3 linolenic acid has been destroyed by processing, and is also unlike most vegetable oils that contain only a small amount of this important fatty acid.

Dietary cholesterol

Dietary cholesterol is very important in this scenario, as evidenced by the NCEP/AHA dietary recommendations to reduce the daily intake to below 300 or 200 mg (depending on individual risk). In fact, dietary cholesterol increases the body's sensitivity to SFA, so that maximising its removal can substantially reduce much of the negative influence of

SFA on the lipoprotein profile. PUFA, on the other hand, are the major fatty acids able to actually offset the negative impact of dietary cholesterol because linoleic acid (18:2 n-6) enhances the removal of plasma LDL, the main lipoprotein that is increased by dietary cholesterol.

Monounsaturates

From our results and the analysis of others, MUFA have been found to be essentially neutral in terms of their lipoprotein profile, and therefore are perhaps the best source of fatty acids to use as 'filler' in the dietary fat load. This is true to some extent, but the critical issue remains as to how much SFA and PUFA should be consumed to achieve the best LDL/HDL ratio. As our comparison between olive oil and various fat blends in cynomolgus monkeys has revealed, a high MUFA intake at the expense of PUFA and SFA does not counter the presence of dietary cholesterol very well and leads to an increased LDL/HDL ratio relative to a balanced SFA : MUFA : PUFA ratio that allows for a higher PUFA intake. Thus, fat blends incorporate a better fatty acid balance than olive oil alone.

Lipoprotein profile

How the individual (normocholesterolaemic *vs* hypercholesterolaemic) fits into this story is an important consideration. Obviously, more research is needed, but it appears that the fundamental response to the AHA balanced fatty acid diet is similar in both types of individuals. That is, a 1:1.5:1 balance in SFA : MUFA : PUFA appears to be important to both groups for generating the ideal LDL/HDL ratio. In absolute terms, the response by the hypercholesterolaemic individual is more dramatic, but the person with a normal cholesterol value responds in the same manner, just not to the same degree.

LDL/HDL ratio

It is true that an elevated cholesterol level (>180 mg/dL) begins to increase the risk of CHD. Most of the increase above 180 mg/dL is in the LDL-C pool, and this lipoprotein is the one that deposits during arterial cholesterol build-up. On the other hand, people (and essentially all animals) with naturally high levels of HDL-C do not develop CHD, primarily because this lipoprotein transports cholesterol back to the liver for excretion in bile. HDL in the arterial wall also blocks LDL oxidation, thereby preventing the local damage induced by LDL accumulation. Thus, the 'bad' and 'good' connotation for these two lipoproteins becomes apparent, and it is easy to understand why one wishes to have the lowest LDL-C and highest HDL-C (i.e., lowest LDL/HDL ratio) for any given TC value.

Brandeis–PORIM patent

The novel finding from nutritional research at Brandeis University and Palm Oil Research Institute of Malaysia is that the 1:1:1 balance in SFA : MUFA : PUFA recommended over the years by the AHA actually induces the best lipoprotein profile in animals and humans. This seems to be

true for all levels of fat intake normally consumed in Western diets (20–40% of total calories). Significant deviation from 1:1.5:1, such as too low SFA or too high MUFA or PUFA, induces a less desirable lipoprotein profile, even if the total plasma cholesterol is lower. Our tested fat blends were specifically designed to adhere to this 1:1.5:1 balance while removing all TFA. Several human studies and epidemiological reports indicate that *trans* are 'equal to or worse than' the SFA they were designed to replace. In fact, some of the deleterious effects attributed to SFA over the years were very probably the result of substitution by TFA. Future research will undoubtedly examine this possibility. The following published reports serve to substantiate the above points.

Both SFA and PUFA are required for the optimal LDL/HDL ratio

The first report tested the hypothesis that providing either too few SFA or PUFA in the diet could be detrimental to the HDL or LDL level, respectively (Fig. 1).[1] Three fats were fed in the whole-food diets of 23 young men with normal cholesterol values, providing two-thirds of the daily fat load from supplemented dietary oils (31% fat energy). The dietary fat was initially balanced as in the AHA Step I with a 10:13:8 ratio of SFA : MUFA : PUFA in the final diet, followed by a high-MUFA low-SFA (6:17:8) or high-SFA, low-PUFA (13:14:4) diet. The first represented a blend of soybean oil, palm oil and canola oil whereas the other two fats were supplied as canola oil or palm olein. All three fats produced about the same normal TC value, but the AHA blend produced the highest HDL and lowest LDL, so that the LDL/HDL ratio was significantly enhanced by the AHA balanced blend of SFA : MUFA : PUFA. Therefore, neither too low SFA nor too low PUFA is adequate, and MUFA are no substitute for either. Rather, one needs a balance of PUFA (to lower LDL) and SFA (to raise HDL) for the best TC and LDL/HDL profile, at least when following an AHA Step I diet at 30% en fat. The 8:12:8 balance for SFA : MUFA : PUFA inherent in the current NCEP and AHA guidelines for 30% en from fat appears to be the best advice for the average individual.
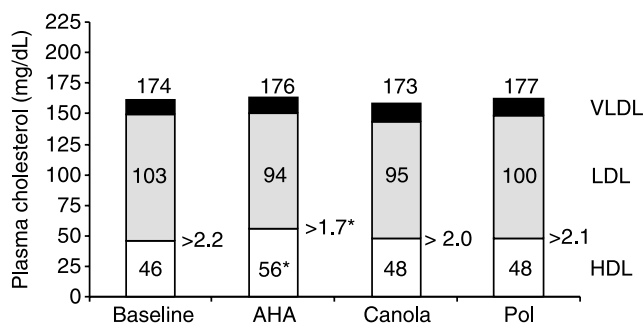
High PUFA or high SFA cause lipoprotein imbalance

The second study[2] reports data that closely resemble that of Sundram *et al.*[1]. The run-in diet, which was 'AHA Step I' (no other details provided) generated the best LDL/HDL ratio because the HDL level was significantly higher than with the other two diets. The other diets were either much more saturated (palm oil) or much more polyunsaturated (sunflower and olive oils) than the AHA recommended balance of 1:1.3:1. Because the subjects were hypercholesterolaemic, the SAT diet raised LDL significantly, unlike in the report of Sundram *et al.*[1] where subjects were normolipaemic. This rendered the LDL/HDL ratio for the SAT diet much worse. But the polyunsaturated fat (POLY) diet contained too much 18:2 and not enough SFA. Although it lowered LDL to a level equal to that found with the AHA Step I balanced fatty acid profile of the run-in diet, it also lowered HDL. The latter result was very similar to the Schaefer data where too much PUFA also seriously depressed HDL.[3] On the other hand, the SAT diet provided too much 16:0, which raises LDL in hypercholesterolaemic individuals. Therefore, the AHA Step I diet at 30% en fat and 1:1.3:1 generates the highest HDL and best LDL/HDL ratio, even in hypercholesterolaemic subjects.

PUFA intake is critical for the best LDL/HDL ratio

Another study[4] addressed two questions: (i) whether a low-fat diet (20% fat energy) would improve relatively normal TC values in 31 adult women; and (ii) whether it matters much if dietary fatty acids are balanced between SFA : MUFA : PUFA in either a high-fat (40% en) or a low-fat (20% en) situation (i.e., considerably above or below the AHA Step I diet objective of 30% fat energy, but with or without the 8:12:8 balance in SFA : MUFA : PUFA that the AHA endorses). Several results were apparent (Fig. 2). The dietary polyunsaturated to saturated fatty acid ratio (P/S) was 0.3 in group I ($n = 15$) and 1.0 in group II ($n = 16$). Fatty acid balance had little effect on LDL or HDL at 40% en, primarily because the basal (group I) intake of PUFA (6% en) was close to the amount of 18:2 required for normal lipoprotein metabolism under the circumstances. But the suggested
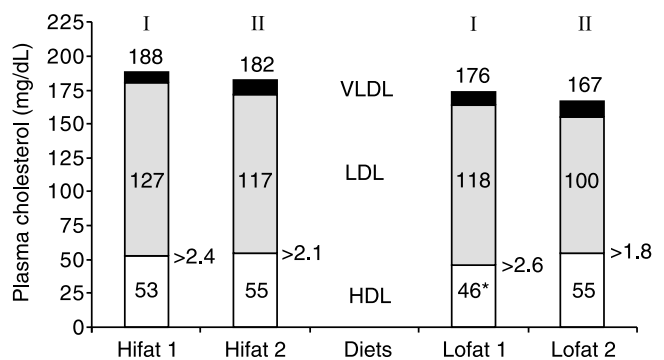

Figure 1. Fatty acid balance improves the LDL/HDL ratio in normolipemic humans. For each diet the % en fat, S:M:P, P/S ratio are as follows: Baseline, 31% en, 12:12:4, P/S 0.3; AHA, 31% en, 10:13:8, P/S 0.8; Canola, 31% en, 6:17:8, P/S 1.3; Pol, 31% en, 13:14:4, P/S 0.4. Modified from reference 1.

Figure 2. LP profile in women at high vs. low fat intake and 0.3 vs. 1.0 p/s ratio. For each diet the % en fat, S:M:P, P/S ratio are as follows: Hifat 1, 39% en, 17:16:6, P/S 0.3; Hifat 2, 39% en, 12:15:12, P/S 1.0; Lofat 1, 19% en, 10:8:3, P/S 0.3; Lofat 2, 19% en, 6:7:6, P/S 1.0. Modified from reference 4.

AHA balance (P/S 1.0) did tend to improve the LDL/HDL ratio slightly at this high-fat intake. However, when consuming the low-fat diet, the balance in fatty acids was exceedingly important because a 1:1:1 ratio prevented the substantial decline in HDL seen with group I, where the typical American fat imbalance (P/S 0.3) resulted in higher LDL and lower HDL. This undesirable impact on LDL and HDL in group I occurred primarily because the absolute intake of PUFA (3% en) was too low for adequate lipoprotein metabolism when total fat supplied only 20% en. The LDL/HDL ratio was much improved by feeding the 1:1:1 fatty acid balance at the low-fat intake (group II) because the 6% en from PUFA was now adequate in absolute terms (i.e., grams 18:2/day).

Therefore, with dietary fat somewhere between 40% en and 20% en, the proper balance in fatty acid intake becomes exceedingly important for generating the optimal LDL/HDL ratio, that is, the lowest LDL and highest HDL values. As in the report of Sundram et al.,[1] it would appear that a controlled intake of 18:2 PUFA is required to allow for the greatest decline in LDL without also lowering HDL. The particular type of SFA fed in this study was not specified, although an amount of SFA equal to the PUFA resulted in a favourable LDL/HDL response.

Fatty acid balance can selectively lower LDL but not HDL
A report by Schwandt et al.[5] addressed the issue of whether improving the fatty acid balance in the diet of 30 normolipaemic men fed a typical Western diet (fat = 37% en) would enhance their lipoprotein profiles, even after 3 months of comparison feeding. The hypothesis was tested by switching from a P/S ratio of 0.3 to a ratio of 1.0, that is, adopting the AHA balance in SFA : MUFA : PUFA of 1:1:1, even if not including the reduced fat intake recommended by the AHA (30% en). The average entry TC was upper-normal (200 mg/dL) and the level of PUFA intake (5.6% en) is very typical of the USA today. Balancing the P/S to 1.0 by shifting 6% en from SFA to PUFA caused a significant decline in TC and LDL without depressing HDL. This resulted in significant improvement in the LDL/HDL ratio. A design flaw was the failure to designate the specific type of SFA removed. Thus, similar to a subsequent trial,[6] balancing the dietary fatty acid intake over a significant period of time is important, even with a somewhat elevated level of dietary fat (37% en) in normolipaemic subjects, if one wants to lower LDL-C without depressing HDL-C.

Fatty acid balance is more critical than amount of fat
Research conducted by Weisweiler et al. evaluated the importance of dietary fatty acid balance on the lipoprotein profile of 22 nuns (22–55 years, mostly postmenopausal) who had mildly elevated TC (224 mg/dL) at entry.[6] They were fed three dietary fats for 6 weeks each: first, a high-level, saturated fat (42% en, P/S = 0.16); second, that same level of fat with a balanced fatty acid profile (P/S, 1.0), which was accomplished by decreasing SFA (exact profile not provided) and increasing PUFA. The third fat was close to AHA Step I (32% en with a 1:1:1 balanced fatty acid profile) similar to the SFA : MUFA : PUFA balance in the second fat rotation. The results suggest that if one begins with a very unfavourable P/S ratio (0.16 because PUFA was too low) in a high-fat diet (42% en), balancing the P/S ratio according to AHA guidelines improves the TC and LDL/HDL ratio. The new balance between SFA and PUFA decreased LDL and increased HDL. However, dropping the fat intake to 32% en with the AHA balance in place did not improve TC or the LDL/HDL ratio further. Therefore, in the 30–40% en range, a balance (adequate PUFA, adequate SFA) seems more critical than total fat. The particular type of SFA was not detailed in this report. Other studies have found that decreasing 12:0 + 14:0 is more important than decreasing 16:0 + 18:0 if the best LDL/HDL ratio is to be achieved at a lower SFA intake (KC Hayes and A Pronczuk, unpubl. data, 1999). Thus, the approximately equal balance of SFA : MUFA : PUFA (1:1.3:1) as recommended by NCEP and AHA is a very important basic consideration at any fat intake for maintaining the best LDL/HDL ratio.

Too high PUFA or too low fat depresses both LDL and HDL
Schaefer et al. have demonstrated what happens to LDL and HDL in normolipaemic (n = 11) and hyperlipaemic (n = 19) subjects fed a very saturated, high-fat diet (P/S 0.2, 40% en) or a very polyunsaturated, high-fat diet (P/S 2.0, 40% en).[3] Subjects were compared to an almost fat-free saturated fat diet (P/S 0.2, 3% en). The questions addressed were: (i) does the response to fat by normocholesterolaemic subjects differ from hypercholesterolaemic subjects?; and (ii) does the lipoprotein profile benefit more from a high-POLY approach to diet modification, or is it better to drastically reduce the fat intake with a high-carbohydrate diet without concern for the fatty acid balance?

The results show that a high POLY diet (P/S 2.0) decreases both LDL and HDL in all subjects. Removing essentially all the fat decreased both LDL and HDL still further. The LDL/HDL ratio did not improve with either tactic, and the general response was similar for both groups of subjects (i.e., normolipaemics and hyperlipaemics). Therefore, although a very high-POLY diet will decrease TC and LDL-C in both normolipaemic and hyperlipaemic subjects, the decline in HDL-C is also substantial. The LDL/HDL ratio does not improve. As shown by Weisweiler et al.,[6] if one wishes to maintain HDL and lower LDL to improve the LDL/HDL ratio, a balance between SFA and PUFA is important. The same decrease in LDL-C obtained with very high POLY can be achieved if the SFA : MUFA : PUFA ratio is balanced, but this balanced approach does not depress HDL.

Fatty acid balance is especially critical in low-fat diets
The objective of a study by Nelson et al. was to determine whether the lipoprotein profile would be altered by decreasing fat intake from a high level (39% en) to a low level (22% en) if the P/S ratio was held constant and balanced at

about 1.0.[7] Most studies show that switching to a high-carbohydrate, low-fat diet lowers TC, including both LDL and HDL. Nine normolipaemic men were evaluated in a metabolic ward, but the SFA : MUFA : PUFA ratios were not totally equal between the diets and were either 1.2:1.5:1.0 (high-fat) or 1.0:1.4:1.0 (low-fat), providing P/S ratios of 0.8 and 1.0, respectively.

The results reveal that the TC, LDL-C, and HDL-C were not significantly affected by the low-fat, high-carbohydrate diet, although they tended to be slightly lower than the high-fat period. Therefore, a high-carbohydrate, low-fat diet does not necessarily mean that HDL will decline, provided that the balance between SFA and PUFA is maintained. However, the tendency toward slightly lower HDL at 22% en suggests that the 30% en AHA Step I level might better sustain HDL[1] or that the MUFA intake was allowed to drift up too far relative to SFA and PUFA during the low fat intake. The LDL/HDL ratio might have been improved at low fat (and even at high fat) if the overall balance between SFA : MUFA :PUFA fatty acids had been maintained closer to 1:1:1 for both diets. The dietary P/S ratio is therefore important at any fat intake, but is an especially important determinant of the lipoprotein response at low fat intake (<20–25% en) because it dictates the absolute availability of 18:2. At low fat intakes, a low P/S ratio (<0.5) greatly limits the 18:2 needed to meet metabolic requirements for normal lipoprotein metabolism, especially for lowering the LDL but also for raising HDL. In fact, a SFA : MUFA : PUFA ratio of 1:1.3:1 appears to be superior in such cases.

HDL can increase when total fat intake decreases
It is generally agreed that replacing fat with carbohydrate is associated with a decline in TC, but unfortunately HDL-C also tends to decrease. One of the first studies to show that this does not necessarily occur if fatty acids are balanced was a subgroup from the Oslo study.[8] The original study revealed that reducing total fat, especially SAT and monounsaturated fat (MONO), and dietary cholesterol intakes to about 30% en and <300 mg/day, respectively, greatly reduced TC and LDL-C without decreasing HDL-C in 18 000 men.
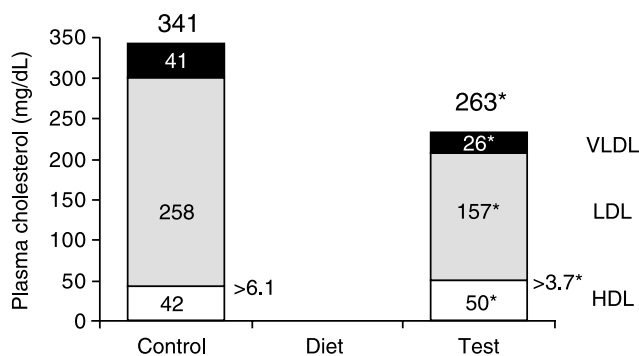
To examine this more closely, 23 diet responders from the original cohort were compared with 23 controls who continued to eat the high-fat baseline diet. Both groups had identically elevated initial blood lipid values. The test group was instructed as to how dietary fat should be lowered from 44% en to about 30% en by focusing on removal of SAT. In the process, a good balance of SFA : MUFA : PUFA was achieved, decreasing from an imbalanced 18:19:7 to 8:12:8. The data demonstrate sharp declines in TC, LDL-C and triglycerides (200 vs 129 mg/dL) with an equally sharp increase in HDL-C (from 42 to 50 mg/dL) (Fig. 3). Thus, removing SFA and MUFA from a high-fat diet decreased LDL-C sharply, but also increased HDL-C when the P/S ratio was rebalanced to 1.0 and the total balance in SFA : MUFA : PUFA approximated 1:1.3:1.

A high-mono diet is not as favourable as a low-mono diet
The original AHA recommendation called for an even balance between SFA : MUFA : PUFA at 30% en from fat. Recently, AHA has recommended a 50% increase in MUFA at the expense of SFA and PUFA. However, a human study on eight normolipaemic men demonstrated the potential downside of exaggerating the MUFA : PUFA ratio too much.[9] The men were fed either 0.5 or 3.0 MUFA : PUFA ratios in two diets in which the P/S ratio was constant at 1.0. The high-MUFA diet produced a TC that was identical to the low-MUFA diet, but LDL-C was elevated ($P < 0.05$) when SFA and PUFA intake got too low. HDL was also lower, so that the LDL/HDL ratio was significantly higher. In addition, the high-MUFA diet induced a 20% rise in triglycerides (Fig. 4). Thus, the high-MUFA diet was inferior to the low-MUFA intake, indicating that a proper balance in SFA : MUFA : PUFA is important for generating the best LDL/HDL ratio. Whereas keeping the P/S ratio at around 1.0 may be the most critical relationship, it would appear that MUFA should not exceed 1.5 times the relative abundance of PUFA and SFA.

A high-mono diet is inferior to a balanced SFA : MUFA : PUFA ratio
The objective of a study in cynomolgus monkeys was to explore the relative importance of the SFA : MUFA : PUFA

Figure 3. AHA step I diet improves the lipoprotein profile of hypercholesterolemic men. For each diet the % en fat, S:M:P, P/S ratio are as follows: Control, 44% en, 18:19:7, P/S 0.4; Test, 28% en, 8:12:8, P/S 1.0. Modified from reference 9.
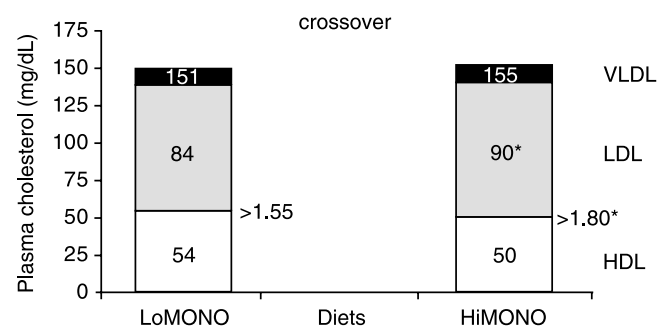

Figure 4. Human lipoprotein response to a low-mono or high-mono diet. For each diet the % en fat, S:M:P, P/S ratio are as follows: LoMONO, 28% en, 11:6:11, P/S 1.0; HiMONO, 28% en, 5:18:5, P/S 1.0. Modified from reference 7.

balance in regulating TC and the LDL/HDL ratio when consuming 30% en and less than 300 mg/day cholesterol (equivalent to human AHA Step I diets) (KC Hayes and A Pronczuk, unpubl. data, 1999). Similar to the human results just cited[9] and compared to an American fat blend derived from butter and canola oil, an unfavourable imbalance developed in the LDL/HDL ratio when dietary SFA and PUFA were about equal but too low relative to MUFA. Specifically, AHA Step 1 diets (diets 1X and 1H), with P/S ratios close to 1.0, represented blends of four and three oils, respectively. The third test diet was olive oil alone with a fairly favourable P/S ratio of 0.75. The TC response and the LDL/HDL ratio were much improved when the relative intakes of SFA : MUFA : PUFA were fully balanced by either of the Step 1 diets, that is, the specific oil blend did not make a difference. Therefore, while the dietary P/S ratio is a rough indicator of how a fat will affect the plasma LDL/HDL ratio, it would appear that an approximate balance of SFA : MUFA : PUFA is also critical, at least at a 30% en fat intake.

Progressive removal of SFA lowers both LDL-C and HDL-C

This carefully designed and executed study examined the effect of a two-step selective removal of SFA (4.5% en each step) from a diet initially containing 34% en as fat, while keeping MUFA and PUFA constant.[10] Even though the P/S ratio increased to 1.0 in the process, MUFA intake was twice that of the other two fatty acid classes when the low-fat diet (providing 25% en as fat) was achieved. Removal of 9% en as SFA decreased LDL-C by 12%, but HDL-C was depressed proportionally (Fig. 5). Thus, the indiscriminate removal of SFA (individual SFA not identified) and their replacement by MUFA lowers TC without improving the LDL-C/HDL-C ratio, at least when the MUFA intake substantially exceeds that of SFA or PUFA.

SFA are best represented by 16:0 and 18:0 fatty acids

As a follow up to the above report,[10] it was decided to determine whether it matters which SFA remain when the stepwise removal of SFA was completed. In addition, would
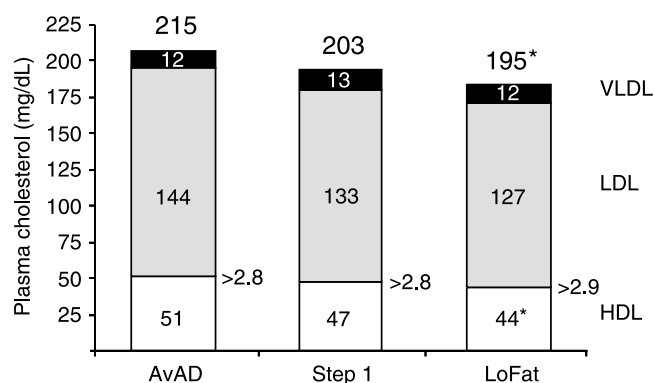

Figure 5. Human lipoprotein response to stepwise removal of sfas (delta 1). For each diet the % en fat, S:M:P, P/S ratio are as follows: AVAD, 34% en, 15:13:6, P/S 0.4; Step 1, 29% en, 9:13:6, P/S 0.7; Lfat, 25% en, 6:13:6, P/S 1.0. Modified from reference 10.

rebalancing SFA : MUFA : PUFA have an impact on the lipid profile at 25% en from fat? In other words, when reducing dietary SFA, does it matter which SFA are removed? Our experiment with cebus monkeys essentially replicated the human study except that after 25% en was achieved, the low SFA level was increased to rebalance the SFA : MUFA : PUFA ratio.[11] In this rebalance, SFA were adjusted to present either only 16:0 + 18:0 or primarily 12:0 + 14:0. The data reveal that removal of fats containing 12:0 + 14:0 (leaving 16:0 + 18:0-rich fats) leads to a greater reduction in TC and LDL-C and results in an improved LDL/HDL ratio. This is because 12:0 + 14:0-rich fats tend to increase LDL. Thus, when balancing the SFA : MUFA : PUFA ratio in a fat blend, it is preferable to utilise a 16:0 + 18:0-rich fat as the SFA source rather than one rich in 12:0 + 14:0, in terms of generating the best LDL/HDL ratio.

Exercise improves the lipoprotein response during the step 2 diet

Stefanick et al.[12] addressed the question of how the AHA Step 2 diet (25% en as fat, <7% en SFA, <200 mg diet cholesterol) compares with the AHA Step 1 diet (<30% en as fat, <10% en SFA and PUFA, <300 mg cholesterol), and whether exercise played a role in TC and the LDL–HDL relationship. The results indicate that exercise did not have much of an effect until the total fat decreased to 25% en and the SFA : MUFA : PUFA ratio was rebalanced. HDL was then minimally affected but LDL decreased substantially so that the LDL/HDL ratio improved.

TFA are worse than SFA in humans

Trans fatty acids are generated when vegetable oils are partially hardened by hydrogenation to replace naturally saturated fats in the diet. Because TFA typically are monounsaturated, it was thought they exerted a neutral effect on cholesterol metabolism and other biological functions. However, more recent data have revealed a negative influence on lipoproteins and possibly other functions as well.

To examine this point more directly, trans 18:1 n-9 (elaidic acid) was compared head-to-head with the most cholesterol-raising SAT and the neutral cis 18:1 n-9 (oleic acid) in humans.[13] The four fats representing these fatty acids were tested in natural diets of normocholesterolaemic subjects who each consumed all four diets over a 16-month period. The data reveal that TFA proved to be just as cholesterol-elevating as the worst SFA (12:0 + 14:0), and TFA had the most detrimental impact on LDL-C (greatest increase) while uniquely depressing HDL (Fig. 6). Therefore, when assessed by direct comparison with specific fatty acids, TFA proved worse than the SFA they were designed to replace.

Conclusion

In summary, as stated for years, dietary fat composition does, indeed, have a major impact on the plasma lipid
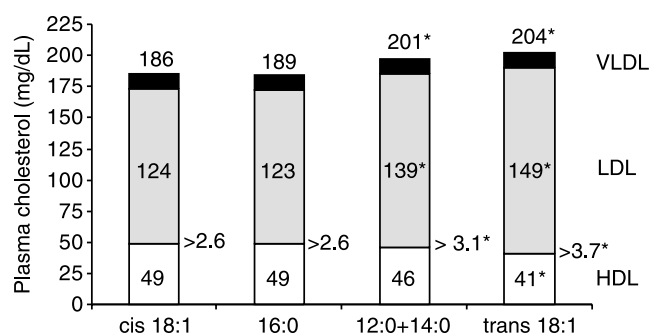
Figure 6. Comparison between cis 18:1, 16:0, 12:0+14:0, and trans 18:1 in normolipemic humans. For each diet the % en fat, S:M:P, P/S ratio are as follows: cis18:1, 32% en, 10:17:5, P/S 0.5; cis16:0, 32% en, 14:14:4, P/S 0.3; cis 12:0+14:0, 33% en, 17:10:6, P/S 0.4; trans 18:1, 31% en, 7:11/7:6, P/S 0.8. Modified from reference 13.

profile. However, beyond the typical call for a better balance between SFA and PUFA, it is apparent that MUFA figures in the final outcome if one attempts to induce the best plasma LDL/HDL profile in humans. Between dietary fat intakes of 20–40% en, the ideal balance would seem to approximate 1:1.3:1 for SFA : MUFA : PUFA.

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