Optimal macronutrient balance

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There is at present a justifiable debate as to the optimum level of total dietary fat which will reduce the risk of obesity without an elevation of plasma triacylglycerol or a depression of plasma HDL-cholesterol. Total plasma cholesterol and LDL-cholesterol levels are lowered and risk of fatal myocardial infarction is lowered when either saturated or trans-unsaturated fatty acids are replaced isomerically by either monounsaturated or polyunsaturated fatty acids. The triacylglycerol-raising and HDL-lowering effects of low-fat high-carbohydrate diets can be overcome with low intakes of n-3 polyunsaturated fatty acids and moderate exercise. Whilst a reduction in dietary fat is being attained in many countries, the reduction is uniform across all fatty acids, leaving dietary fat composition unchanged. The ability of low-fat diets to reduce cholesterol and cause a fall in body weight is not influenced by the carbohydrate ratio starch:sugars in the diet. However, weight-gain susceptibility to high intakes of dietary fat and the plasma cholesterol responsiveness to diet are considerably influenced by common genetic polymorphisms.

Dietary fat: Dietary fatty acids; Dietary carbohydrate: Diet and genetics

In considering the optimal balance of macronutrients in the context of a symposium on optimal nutrition, two caveats immediately spring to mind. One is that it is beyond the scope of a brief presentation to address issues which are regularly addressed by committees of experts often over several years. A second is the question of ‘optimal for which purpose?’; reproduction, lactation, growth, health, ageing or physical activity. For the purposes of the present paper the focus will be on optimal macronutrient balance for health, and the macronutrients dealt with will be fat (excluding n-3 polyunsaturated fatty acids (PUFA)) and carbohydrate, since protein, fibre and n-3 PUFA are dealt with elsewhere in the symposium. By way of concluding this introduction, genetic variation in response to dietary intervention will also be considered as a factor impinging on the concept of optimal nutrition.

Dietary fat and dietary carbohydrate level

Most expert committees (Food and Agriculture Organization/World Health Organization, 1994) which have advised the public on optimal levels of dietary fat have advocated a reduction in the proportion of dietary energy from fat. The benefits are a reduction in plasma levels of both total cholesterol and LDL-cholesterol and a reduction in the risk of developing obesity. There is ample evidence in the literature to show that a reduction in total fat intake lowers blood cholesterol. However, reductions in total fat intake are invariably accompanied by reductions in the intakes of cholesterol-raising saturated fatty acids (SFA). Plasma LDL-cholesterol can readily be reduced without a reduction in fat intake, provided SFA intake is reduced. Thus, if plasma LDL-cholesterol is the chosen end point, dietary fat level is not a critical issue. Indeed, if fatal or non-fatal myocardial infarction is the end point, the data from the Nurses Health Study (n = 80,082 adult women) would suggest that there is no difference across quintiles of total fat intake (% energy) in the relative risk of CHD when adjusted for other dietary, lifestyle and clinical variables (Hu et al. 1997). Moreover, it is argued that a reduction in total fat intake, accompanied by a rise in carbohydrate intake, leads to a rise in plasma triacylglycerol (TAG) and a fall in plasma HDL-cholesterol which, certainly in women, would increase the risk of CHD (Katan et al. 1997). Consequently it is argued that the level of dietary fat should not be the focus of reduction, but rather the level of cholesterol-raising SFA should be the central public health nutrition message. Two recent studies (Saris et al. 1998; Turley et al. 1998) have failed to demonstrate a rise in plasma TAG and a fall in plasma HDL-cholesterol with low-fat high-carbohydrate diets. Turley et al. (1998) rotated thirty-eight healthy subjects through a standard Western-type diet (36 % energy...

Abbreviations: Apo, apolipoprotein; MUFAs, monounsaturated fatty acids; P diet, high-polyunsaturated fatty acid diet; PUFA, polyunsaturated fatty acids; S diet, high-saturated fatty acid diet; SFA, saturated fatty acids; TAG, triacylglycerol.

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from fat, 43 % energy from carbohydrate) and a high-
carbohydrate diet (22 % energy from fat, 59 % energy from
carbohydrate), with the subjects given advice on how to
select a low-fat high-carbohydrate diet. No significant effect
on either plasma TAG or HDL-cholesterol was observed.
The authors concluded that their study differed from other
studies in that the high-carbohydrate diet was freely
selected, which compared with studies which observed a
rise in plasma TAG where subjects were given either
prepared foods, or formula feeds in metabolic wards. That
argument seems somewhat simplistic, since many other
studies using similar experimental approaches have noted a
rise in plasma TAG where subjects self-selected foods
according to advice on how to achieve a low-fat high-
carbohydrate diet (Roche & Gibney, 1998). The concept
that the method of achieving a low-fat, high-carbohydrate
diet determines the plasma TAG is not supported by a
second recent study (W Saris, personal communication)
where subjects were each assigned to either a low-fat high-
carbohydrate diet (27 % and 53 % energy from fat and
carbohydrate respectively, or a control diet (36 % energy
from fat, 46 % energy from carbohydrate) and where the
experimental low-fat diet was largely achieved by subjects
receiving prepared low-fat foods from the investigators. No
significant effect on plasma TAG or HDL-cholesterol was
noted. Thus, it cannot be stated that in all instances low-fat
high-carbohydrate diets will elevate plasma TAG. It may be
that the initial level of plasma TAG is of importance. In the
study of Turley et al. (1998) and in the CARMEN study
(W Saris, personal communication) fasting plasma TAG
levels were 1.41 and 1.60 mmol/l respectively. However, in
the case of Roche & Gibney (1996) and Mensink & Katan
(1987), where low-fat high-carbohydrate diets significantly
elevated plasma TAG levels, the fasting plasma TAG levels
were much lower (0.95 and 0.86 mmol/l respectively).
Clearly, it is a matter of importance in nutrition policy
development to clarify the factors which determine plasma
TAG responsiveness to low-fat high-carbohydrate diets.

In terms of influence on body weight, there is extensive
experimental and epidemiological evidence that high-fat
diets predispose to obesity (Gibney, 1995; Prentice & Pop-
nett, 1996). However, a counter-argument to this evidence is
that whereas obesity levels have increased by 30 % in the
USA between 1976 and 1986, total % energy from fat has
actually fallen. These arguments are somewhat incomplete
if the issue of physical activity is not considered, since Prent-
tice & Jebb (1995) have elegantly demonstrated that the rise
in obesity in the UK parallels a rise in sedentary lifestyle, as
indicated by the long periods spent watching television and
videos, and the numbers of cars per household. It may well
be that above a certain level of dietary fat, which may indeed
be about the level now prevailing in the USA, physical inac-
activity is the primary cause of weight gain. Those researchers
who argue against a role of high-fat diets in the development
of obesity have presented data showing that long-term
adherence to a low-fat diet leads to weight losses of only
0.8–2.6 kg (Katan et al. 1997). However, small changes in
mean population body weight may be associated with a
significant shift in extremes of the distribution of weight in
an environment with a moderately high level of dietary fat
and low level of physical activity. As to the optimum level
of total fat in the diet, further research is needed to explore
why in some studies, but not others, a low-fat diet induces
increased plasma TAG and reduced HDL concentrations. If a
low-fat diet includes a low level (approximately 1.0 g/d) of
n-3 long-chain PUFA, then the TAG-raising effects of low-
fat high-carbohydrate diets are negated (Roche & Gibney,
1996). However, unless nutrition policy can successfully
raise n-3 PUFA levels, it is necessary to continue to debate
the advantages and disadvantages of low-fat diets and to
continue to research this complex issue.

Genes, dietary fat and obesity

In addition to diet and physical activity, a third dimension to
the debate of lifestyle and body weight is genetics. Saltzman
et al. (1997) studied the effects of low-fat and high-fat diets
on energy intake and substrate oxidation in a strictly-
controlled study over 9 d in seven pairs of identical twins. It
is important to note that both the low- and high-fat diets
were of equal energy density. In the case of three twin pairs
there was an increase in energy intake with the high-fat diet
over the low-fat diet. In three twin pairs the opposite was
seen, and with one twin pair no effect of dietary fat on
energy intake was noted. Although this was a study where a
small group of identical twins were subject to detailed meta-
bolic investigation, it is supported in the provision of
evidence for a genetic susceptibility to overeating on a high-
level diet, leading to obesity, by a prospective epidemiological
study of 361 Swedish women over 12 years of follow-up
(Heitmann et al. 1995). Mean overall BMI gain was just
under 1 kg/m². However, the subjects were divided into
two groups who were overweight (BMI 29 kg/m²) and those who
were normal weight (BMI 22 kg/m²) at baseline, and each of
these groups were further subdivided into those with at least
one parent overweight and those with no parent overweight.
Increasing dietary fat intake had no effect on BMI in any
group other than the one overweight at baseline and with at least
one parent overweight. Even then, the elevation in
BMI over time occurred only at the 90th percentile of fat
intake. Thus, there exists some evidence that obesity may
occur with moderately-high-fat diets, and this occurrence of
obesity may depend on genetic makeup but almost certainly
depends on physical activity levels. Genetic factors may not
only play a role in determining the risk of developing
obesity, but may also determine the risk of obesity-related
morbidity. Thus, Uusitupa et al. (1996) examined fasting
plasma insulin levels in women with waist circumferences
above or below 1.02 m. In each instance the women were
identified for their apolipoprotein (Apo) E phenotype. Those
women with the ApoE 3,2 phenotype fasting insulin was doubled with
increasing waist size. Clearly, future research will identify
further genetic determinants of obesity co-morbidities.

Composition of dietary fat

As indicated in the preceding section, there is ample
evidence to show that a reduction in the level of the SFA

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will reduce LDL-cholesterol, irrespective of dietary fat level. Dietary fatty acid composition is not just relevant to plasma LDL-cholesterol but also to the coagulation system from platelet function to Factor VII activity. Several studies using different approaches have failed to find a role for different dietary fatty acid patterns on different aspects of the coagulation system (Roche & Gibney, 1997; Temme et al. 1998), while other studies have provided data to suggest that certain aspects of the coagulation pathway are fatty acid-sensitive (Mitropoulos et al. 1994). To try to examine the role of individual dietary fatty acids in each of these spheres of risk of CHD is too complex an issue, since the relative importance of each of these spheres for CHD cannot be readily established. An alternative approach is to examine epidemiological data where fatal or non-fatal myocardial infarction is the outcome. Ha et al. (1997) examined the independent effects of total, SFA, PUFA and monounsaturated fatty acids (MUFA) on the risk of CHD in a prospective (14-year follow-up) study of 80,082 women. When all lifestyle, clinical and non-lipid dietary variables were controlled for in a multivariate model the following were noted: if 5% energy from SFA was replaced with 5% energy from carbohydrates, CHD risk fell by about 15%; if 5% energy from SFA was replaced with 5% energy from MUFA or PUFA, the reductions in CHD risk would be 30 and 45% respectively. The greatest reduction in CHD risk (>50%) was achieved where 2% energy from trans-unsaturated fatty acids was replaced with MUFA or PUFA. In effect, the evidence suggests that reducing SFA, and particularly trans-unsaturated fatty acids, by replacement with either MUFA or PUFA while maintaining carbohydrate:fat value constant will provide optimal benefit in terms of CHD.

The two issues of % energy from fat v. fatty acid composition of dietary fats need also to be examined in the context of prevailing patterns of dietary fat intake. Table 1 provides data on the composition of dietary fat in several EU countries at low and high levels of dietary fat intake. It is evident that in northern European countries, the composition of dietary fat remains unchanged, irrespective of the level of dietary total fat. In other words, when populations choose lower-fat diets, they lower their intakes of all categories of fatty acids equally such that fatty acid composition remains unchanged. The same situation is broadly true of southern EU countries. Clearly, the present strategy is tending to favour retention of existing fatty acid patterns, and public health nutrition policy needs to review whether this outcome is a cause for concern.

Genes, dietary fatty acids and plasma cholesterol
It has long been recognized that some individuals respond better than others to dietary and indeed pharmacological intervention for risk-factor reduction. More recently, the contribution of genetics to this variation in response has become clearer. Cox et al. (1995) rotated sixty-seven healthy subjects through high-fat diets (38% energy from fat) which were either high in PUFA (P diet) or high in SFA (S diet). The subjects followed each diet twice in either an SPSP or PPS cycle. Of the sixty-seven subjects, twenty-five (37%) were consistent hyper-responders, twenty-one (31%) were consistent minimal responders and twenty-one (31%) were variable responders. Fielding et al. (1995) compared the responses of Caucasians and non-Caucasians to diets high (600 mg) or low (200 mg) in dietary cholesterol, where each of these diets was subdivided into a high (0.8) or low (0.30) PUFA:SFA value. At low levels of dietary cholesterol, the dietary PUFA:SFA value made no difference to non-Caucasians in terms of plasma cholesterol. At higher cholesterol levels in the diet, the plasma cholesterol response differed slightly in the non-Caucasians consuming the low PUFA:SFA (increased by 0.28 mmol/l) and the high PUFA:SFA (increased by 0.41 mmol/l) diets. However, the corresponding values for Caucasians on the high cholesterol intake were increases of 0.47 and 0.78 mmol/l. Both studies indicate within and between ethnic group variation in respect of their response to the effects of dietary fat variation on plasma cholesterol. Moving from ethnic variation to genetic variation, Ordovas et al. (1995) have reviewed the effect of ApoE phenotype on dietary intervention to lower LDL-cholesterol. Four studies showed no effect of ApoE2 phenotype where the only dietary change was in cholesterol level. In contrast ApoE2 phenotype compared with non-ApoE2 phenotypes showed significantly

### Table 1. The fatty acid composition of dietary fat (g/100 g) at high and low levels of total dietary fat intake in several EU countries

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<th>Low total dietary fat</th>
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<td>% Energy from fat</td>
<td>Dietary fat composition</td>
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<td>SFA   MUFA  PUFA</td>
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<td>43</td>
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<tr>
<td>Belgium</td>
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<td>Finland</td>
<td>Valsta (1999)</td>
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<td>Germany</td>
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<td>The Netherlands</td>
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<td>Southern EU</td>
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<td>Greece</td>
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<td>Portugal</td>
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NA, not available; SFA, saturated fatty acids; MUFA, monounsaturated fatty acids; PUFA, polyunsaturated fatty acids.
different LDL changes with diets where the level of fat (ten studies) or the type of fat (two studies) were altered. Pajakanta et al. (1996) studied eighty-seven subjects on a low-fat diet (24 % energy from fat) with a low level of SFA (7 % energy from fat). Of the subjects 89 % had the ApoB signal peptide (del/del) polymorphism, and this group showed no response in terms of LDL- or HDL-cholesterol to a low-fat low-SFA diet. Approximately 15 % of subjects had the X/X' ApoB (X bal) polymorphism, and these subjects did not respond in terms of blood lipids (HDL and LDL) to the low-fat low-SFA diet. Humphries et al. (1996) found that the H H' (Hind III) polymorphism of lipoprotein lipase (PC 3.3.1 3.4) led to a 50 % higher response to a high-SFA diet than those with the H'H' allele. Clearly, as our understanding of the genetic determinants of dietary intervention to improve plasma lipid increases, the efficacy of clinical nutrition intervention will improve. However, it is unlikely to influence public health nutrition programmes.

**Composition of dietary carbohydrate**

The two main dietary carbohydrates are starch and sucrose. Conventional wisdom held starch to be the nutritionally more favourable of the two carbohydrate sources, but when the two sources are compared in experimental and epidemiological studies, this conventional wisdom is shown to be unjustified. Van Dokkum et al. (1991) studied the effect of low-fat, high PUFA:SFA diets with either 15 or 21 % energy from sugars and found both to be equally effective in lowering plasma total, LDL- and HDL-cholesterol. More recently, the multi-centre CARMEN study compared low-fat diets where starch:sugar value was varied (W Saris, unpublished results). They found no significant differences between the two diets over a 6-month period in terms of effects on blood lipids or body weight. Both diets were equal in their cholesterol-lowering weight-reducing properties. Several studies have shown that % energy from dietary fat and dietary sugars are inversely proportional (Gibney, 1990; Bolton-Smith & Woodward, 1994) and the latter authors have shown clearly that 7 % energy from sugars falls and 5 % energy from fat rises, the incidence of obesity rises. As the relative contributions of fat and sugar vary, the level of starch remains constant, as indeed do levels of micronutrients. Flynn et al. (1996) have used UK dietary data to show that about 80 % energy is provided from staple foods (bread, cereals, rice, potatoes, pasta, meat, poultry, fish, fruit and vegetables) and that these staple foods provide > 95 % of most micronutrient intake. The remaining 20 % energy is provided by pure-fat zero-sugar foods (fats, oils) and by pure-sugar zero-fat foods (sugar, soft-drinks and sugar confectionery). Individuals move along the sugar-fat see-saw according to their taste preferences, without any effect on protein, starch, fibre or micronutrient levels in their diet. Thus, there seems little justification for providing any advice to specifically alter the present sugar:starch balance in the diet.

**Conclusion**

The single biggest requirement for improving macronutrient balance is to lower intakes of SFA and trans-unsaturated fatty acids. Whether this reduction should be accompanied by a reduction in fat intake is still a subject for debate. At present there seems little evidence to suggest that the starch:sugar value in Western diets should be altered.

**References**


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