Review Article

Support of drug therapy using functional foods and dietary supplements: focus on statin therapy

Simone Eussen1,2, Olaf Klungel2*, Johan Garssen2, Hans Verhagen1, Henk van Krane1 and Cathy Rompelberg1

1National Institute for Public Health and the Environment (RIVM), PO Box 1, 3720 BA Bilthoven, The Netherlands
2Utrecht Institute for Pharmaceutical Sciences, PO Box 80082, 3508 TB Utrecht, The Netherlands

(Received 26 March 2009 – Revised 15 September 2009 – Accepted 5 November 2009 – First published online 3 March 2010)

Functional foods and dietary supplements might have a role in supporting drug therapy. These products may (1) have an additive effect to the effect that a drug has in reducing risk factors associated with certain conditions, (2) contribute to improve risk factors associated with the condition, other than the risk factor that the drug is dealing with, or (3) reduce drug-associated side effects, for example, by restoring depleted compounds or by reducing the necessary dose of the drug. Possible advantages compared with a multidrug therapy are lower drug costs, fewer side effects and increased adherence. In the present review we have focused on the support of statin therapy using functional foods or dietary supplements containing plant sterols and/or stanols, soluble dietary fibre, n-3 PUFA or coenzyme Q10. We conclude that there is substantial evidence that adding plant sterols and/or stanols to statin therapy further reduces total and LDL-cholesterol by roughly 6 and 10 %, respectively. Adding n-3 PUFA to statin therapy leads to a significant reduction in plasma TAG of at least 15 %. Data are insufficient and not conclusive to recommend the use of soluble fibre or coenzyme Q10 in patients on statin therapy and more randomised controlled trials towards these combinations are warranted. Aside from the possible beneficial effects from functional foods or dietary supplements on drug therapy, it is important to examine possible (negative) effects from the combination in the long term, for example, in post-marketing surveillance studies. Moreover, it is important to monitor whether the functional foods and dietary supplements are taken in the recommended amounts to induce significant effects.

Combination therapy: Dyslipidaemia: Statins: Functional foods

The world market for functional foods (FF) and dietary supplements (DS) is expanding rapidly. In 2010 FF are expected to represent 5 % of the total global food market(1) and the market for DS is estimated at more than $60 billion worldwide(2). In general, the target population of FF or DS is healthy individuals with slightly elevated risk factors or some physical discomfort. However, due to the fast growing market of FF or DS and the accompanying strong advertising and marketing, also patients on medication may be stimulated to use FF or DS. This may have several consequences for the quality of drug treatment as stated by de Jong et al. with the example of the combined intake of plant sterols and/or stanols and statins(3). Whereas they addressed the additive effect of plant sterols and/or stanols on reducing LDL-cholesterol values in patients on statin treatment, their main focus was the possible negative aspects of the combination, such as unfavourable effects on patient adherence with drug treatment and increasing the potential for food–drug interactions.

In the present review we will focus on the possible beneficial effects that FF or DS may have on drug therapy. Because of the large number of subjects treated suboptimally with statins (hydroxymethylglutaryl CoA (HMG-CoA) reductase inhibitors)(4) and the availability of several FF and DS possibly contributing to the beneficial effects of statin treatment, we will put special emphasis on this group of drugs.

In theory, FF or DS may support drug therapy in three different ways.

First, FF or DS may add to the effect that a drug has in reducing risk factors associated with certain conditions or diseases. For the example of statin therapy, statins reduce LDL-cholesterol by 18–55 % (mean absolute LDL-cholesterol reduction: 1.8 mmol/l)(5–8) and plant sterols and/or stanols and soluble dietary fibres are thought to reduce LDL-cholesterol levels even further when added to the statin treatment.

Second, certain FF or DS may improve risk factors associated with the condition, other than the risk factor that the drug...
is dealing with. In our example, statins are highly effective in lowering total and LDL-cholesterol, but statin monotherapy may not be sufficient to reach goals for TAG concentrations. Depending on the type of statin and its dose, TAG are lowered only by 7–30\%.(5) Supplemeting patients with n-3 PUFAs will lower TAG and might improve statin therapy, since both cholesterol and TAG levels are lowered.

Third, FF or DS may be capable of reducing drug-associated side effects, for example, by restoring depleted compounds. With statin treatment, adverse events such as musculoskeletal complaints have been reported in 1–7\% of statin users(9) and it has been hypothesised that statin-induced coenzyme Q10 (CoQ10) deficiency is involved in this. Supplementing CoQ10 might reduce musculoskeletal complaints. Besides, in patients who reach recommended goals for risk factors but experience side effects with drug use, combination therapy of the drug and a FF or DS might be an alternative with the potential of reducing the drug dose and as a result the side effects, while levels of risk factors remain constant. Subsequently, it is conceivable that patients experiencing fewer side effects will have a better adherence to drug treatment. Adherence might also be higher with the combination therapy of a FF or DS and a statin compared with a multitudr therapy, as patients might be more willing to slightly modify their diet by replacing normal food items with comparable FF, compared with taking another drug; patients’ perception of overmedication has been found to correlate with self-report of decreased adherence(10). Other advantages of the combination therapy with FF or DS compared with multitudr therapy are the lower drug costs and the reduced risk for interactions and serious side effects(11).

For the present review, we reviewed the data from clinical and observational studies that have investigated the effects of the use of FF or DS in patients on statin treatment. We selected four categories: FF or DS containing (1) plant sterols or stanols, (2) soluble dietary fibre, (3) n-3 PUFAs, and (4) CoQ10. We investigated whether these FF or DS have been demonstrated to support statin therapy in one of the three ways described above.

The present review should not be viewed as comprehensive in covering all possible beneficial combination therapies of FF or DS and statins. Rather, the authors’ intent is to focus on different mechanisms of action by which FF or DS may support statin treatment and to provide a full coverage of the literature of the examples of combination therapies given.

### Literature search

Computerised searches for relevant articles in the PubMed electronic database were performed between March and August 2008, using Medical Subject Heading (MeSH) terms or text words combi*, supple* or interact* with statin*, antihyperlipidaemic agents, anticholesteremic agents or hydroxy-methylglutaryl-CoA reductase inhibitors, and combined to one of the search items for the specific FF or DS as noted in Table 1. The search was limited to articles written in English or Dutch and studies performed in human subjects. Studies conducted in patients with medical conditions other than hyperlipidaemia, for example, cancer or diabetics, were excluded. Relevant articles were selected from the title and abstract. Moreover, additional articles were selected from citations in the publications found. Two authors of this report (S. E. and C. R.) independently reviewed the methodological quality of the included trials using the Jadad scoring system to evaluate the effect of study quality on the observed results. This validated scoring system assigns points for randomisation, double-blinding, and documentation of patient withdrawal, as well as additional points for the appropriateness of the randomisation and blinding methods.(12) Trials scoring 3 points or above, out of a maximum of 5, are generally considered to be of good methodological quality. Discrepancies between the two authors were settled through discussion.

In the following section we will first explain our current understanding of the mechanism of action by which the FF or DS may support statin treatment. Subsequently, the effects of the FF or DS in the healthy population and approved health claims will be discussed and we will summarise the results of clinical and observational studies exploring the combination therapy. Finally, safety aspects of the combination are addressed.

### Plant sterols and stanols

#### Mechanism of supporting statin therapy

Plant sterols and stanols lower serum levels of total cholesterol and LDL-cholesterol through a different mechanism compared with statins. Whereas statins inhibit hepatic cholesterol synthesis, plant sterols and stanols reduce the intestinal absorption of cholesterol. Therefore it is thought that both mechanisms work simultaneously when statins and plant sterols and/or stanols are taken together. It is generally assumed that plant sterols and stanols compete with both dietary and biliary cholesterol for solubilisation into mixed micelles. Because plant sterols and stanols are more hydrophobic than cholesterol, they have a higher affinity for the micelle(13,14). Other mechanisms proposed are the interference with the cholesterol ester-mediated hydrolysis process necessary for absorption, and/or stimulation of the ATP-binding cassette (ABC) transporter expression by plant sterols and stanols(13,15–17). The ABCG5 and ABCG8 transporters actively transport dietary sterol out of the enterocytes back into the intestinal lumen, thereby limiting the amount of sterol absorbed. ABCA1 may also participate in this process.(18) However, studies in plant sterol- and stanol-treated ABCA1- and ABCG5/G8-deficient mice have not demonstrated the

---

**Table 1. Literature search**

<table>
<thead>
<tr>
<th>FF or DS</th>
<th>Literature search</th>
</tr>
</thead>
<tbody>
<tr>
<td>Containing plant sterols or stanols</td>
<td>Phytosterol [MeSH], plant sterol*, plant stanol*, phytosterol*, phytostanol*, stanol ester*</td>
</tr>
<tr>
<td>Dietary fibre</td>
<td>Dietary fibre [MeSH], dietary fibre, soluble fibre, soluble fibre, beta-glucans [MeSH], psyllium [MeSH], oat*, yeast, barley or pectin</td>
</tr>
<tr>
<td>Containing n-3 PUFAs</td>
<td>Omega-3 fatty acids [MeSH], omega-3 fatty acid*, w-3 fatty acid*, n-3 fatty acid*, fish oil or marine oil</td>
</tr>
<tr>
<td>Containing coenzyme Q10</td>
<td>Ubiquinone [MeSH], ubiquinone, coenzyme Q10 or Q10</td>
</tr>
</tbody>
</table>

FF, functional food; DS, dietary supplement; MeSH, Medical Subject Heading.
involvement of these ABC transporters in the reduction of intestinal cholesterol absorption\(^{(19)}\). Differences in \(ABCG5\) and \(ABCG8\) genes between humans and murines might (partly) explain these results\(^{(20)}\).

Decreased cholesterol absorption is associated with a compensatory increase in cholesterol synthesis and an increase in LDL receptor expression. This elevated expression may not only lead to an increased clearance of LDL from the circulation, but also of intermediate-density lipoprotein (IDL). Because IDL is the precursor of LDL-cholesterol, this may ultimately lead to a decreased LDL production. The net result of the lower cholesterol absorption, higher LDL expression and higher endogenous cholesterol synthesis is a reduction in serum total and LDL-cholesterol concentration\(^{(13,17)}\) (Fig. 1).

**Estimated effects of plant sterols and stanols on lipid levels and health claims**

Plant sterol and stanol esters have been incorporated in dairy products such as low-fat margarine, milk and yoghurt. Also cereals, bread and orange juice containing esterified or non-

---

**Fig. 1.** Postulated cholesterol-lowering mechanisms of statins, plant sterols and stanols and soluble dietary fibre. Statins inhibit the enzyme hydroxymethylglutaryl-CoA (HMG-CoA) reductase (1). Plant sterols and stanols compete with cholesterol for solubilisation into mixed micelles (2), leading to a reduced luminal absorption of cholesterol and/or they induce a higher expression of the ATP-binding cassette (ABC) transporter (3), resulting in an efflux of cholesterol back into the intestinal lumen. Both mechanisms lead to an increased faecal output (4)\(^{(13,17)}\). Soluble dietary fibre interrupts with cholesterol and/or bile acid (re)absorption (5), either by binding bile acids or by forming a thick unstirred water layer in the intestinal lumen, leading to an increased faecal output (4). Compensatory up-regulation of the enzyme cholesterol 7-\(\alpha\)-hydroxylase (6) increases the conversion of cholesterol into bile acids. All processes will result in a reduction in the cholesterol content of liver cells what will lead to an up-regulation of LDL receptors (LDLr) and ultimately in an increased clearance of circulation LDL-cholesterol (LDLc) (7)\(^{(59,66,68)}\).
esterified plant sterols or stanols are available on the market. Since 2001, the Adult Treatment Panel of the US National Cholesterol Education Program has recommended the use of plant sterols or stanols (2 g/d) in conjunction with other lifestyle changes to enhance LDL-cholesterol reduction. The panel states that daily intake of 2–3 g plant sterol or stanol esters will reduce LDL-cholesterol by 6–15% (5). Plant sterols and stanols do not have an effect on TAG or HDL-cholesterol levels (21,22). However, two recent meta-analyses evaluated the LDL-cholesterol-lowering effects of plant sterols and/or stanols. Both found that LDL-cholesterol reduction was approximately 0.33 mmol/l for a mean daily intake of 2.1–2.5 g plant sterols and/or stanols (23,24).

Plant sterols and stanols have approved health claims in the USA and in Europe. According to the United States Food and Drug Administration (FDA) there is significant scientific agreement for a consistent, clinically significant effect of plant sterols and stanols on blood total and LDL-cholesterol in both mildly and moderately hypercholesterolaemic (HC) populations. Therefore it has authorised the use of health claims on the association between plant sterol and stanol esters and reduced risk of CHD on food labels. The claims states that ‘Diets low in saturated fat and cholesterol that include two servings of foods that provide a daily total of at least 1.3 g of plant sterol esters or 3.4 g of plant stanol esters, may reduce the risk of heart disease’ (25,26). Based on the scientific evidence available at the time of evaluation, the FDA made a distinction between the amount of plant sterols and plant stanols necessary to lower total and LDL-cholesterol. However, in a clinical trial comparing the cholesterol-lowering efficacy of plant sterols and plant stanols, published shortly after the claim authorisation, no significant difference between esterified plant sterols and plant stanols was found (27).

Since January 2007, Regulation 1924/2006 applies to nutrition and health claims made in commercial communications in all European Union countries (28). The European Food Safety Authority (EFSA) was requested to evaluate scientific data on plant sterols and stanols in accordance with the Regulation and approved in 2008 health claims stating: ‘Plant sterols and plant stanol esters have been shown to lower/reduce blood cholesterol. Blood cholesterol lowering may reduce the risk of coronary heart disease’ (29,30). This advice has been provided to the European Commission and member states who will adopt and authorise the health claims (31).

As concerns safety, the Scientific Committee on Food has assessed plant sterol-enriched foods under the novel foods procedure (European Union Regulation 258/97) (32). They concluded that a maximum level of 8% non-esterified plant sterols, consisting of 30–65% β-sitosterol, 10–40% campesterol, 6–30% stigmastanol and a total of 5% other plant sterols, is safe for human use, also stating that patients on cholesterol-lowering medication should only consume the enriched products under medical supervision (33). Plant stanols were not assessed through the novel foods procedure as these products were consumed in Finland already before 1997 (34).

**Effects of combination therapy with plant sterols and/or stanols and statins**

Vanhanen (35) was the first to conduct a clinical trial towards the effects of sitostanol esters on lipid levels in patients on pravastatin treatment. It was found that the daily addition of 1.5 g sitostanol ester did not lower serum total or LDL-cholesterol after 6 weeks of supplementation. In contrast, subsequent studies, using higher doses, all reported that plant sterols or stanols in combination with various statins have additive effects on total and LDL-cholesterol reduction in patients with (familial) hypercholesterolaemia (FH), as summarised in Tables 2–4.

In Table 2, results of clinical studies are presented that investigated the effects of adding plant sterols or stanols, either in tablet form or incorporated into food products, on lipid levels in patients on (stable) statin treatment. In seven studies, using doses of plant sterols or stanols varying from 1.8 g/d to 6.0 g/d and with intervention periods between 4 and 16 weeks, effects were found ranging from a 6 to 10% decrease for total cholesterol and from a 6 to 15% decrease for LDL-cholesterol. Absolute reductions in total and LDL-cholesterol ranged from 0.31 to 0.62 mmol/l and from 0.30 to 0.67 mmol/l, respectively. The largest reductions were found in a cross-over trial conducted in patients with FH (36), although these reductions are probably partly caused by the low-fat spread as the results were not corrected for changes in a placebo-controlled group and no run-in period on placebo spread was used.

The results for total cholesterol were statistically significant for five out of seven studies (36–40) and either borderline significant (P = 0.052) (41) or non-significant (42) for the two remaining studies. Reductions in LDL-cholesterol were not significantly different between the intervention and control group only in a single-blind study performed by Castro Cabezas et al. (42). This may have been due to the significant reduction in LDL-cholesterol in both the intervention and the control group, caused by the nutritional guidelines and low-fat margarines given to both groups, which may have made it more difficult to find significant differences in reductions between the two groups. The methodological quality of this clinical trial was poor based on components assessed by the Jadad scale. The majority of the studies did not find any significant effects of plant sterols or stanols on HDL-cholesterol or TAG, nor were the effects of plant sterols different compared with the effects of plant stanols. However, Ketomaki et al. found in a study consisting of two consecutive 4-week intervention periods with either a plant stanol ester or a plant sterol ester that only during the sterol ester period LDL-cholesterol increased and TAG levels decreased significantly (36). This study achieved a Jadad score of 3; no placebo-controlled group was included in this study, possibly leading to flawed results.

Table 3 shows the results of studies investigating the differences in effects that plant sterols or stanols have on lipid levels in statin users and non-statin users. All studies have demonstrated that if plant sterols or stanols are added to a statin, the effect on cholesterol reduction is similar (40,43) or even higher (44) compared with that observed with the use of the plant sterols or stanols alone.

De Jong et al. (45) and Wolfs et al. (46) also investigated the cholesterol-lowering effects of plant sterol- and stanol-enriched margarine (no differentiation between plant sterols and stanols) between statin users and non-statin users in a post-marketing surveillance setting over 5 years. These authors suggest that plant sterols and stanols have an additive
Table 2. Clinical studies towards the effects on lipid levels (total, LDL- and HDL-cholesterol and TAG) of the combination therapy with statins and plant sterols or stanols: effects of plant sterols or stanols in statin users

<table>
<thead>
<tr>
<th>Author</th>
<th>Type of study</th>
<th>Jadad score</th>
<th>Subjects</th>
<th>Plant sterol or stanol/ control intervention</th>
<th>Study duration</th>
<th>Total cholesterol</th>
<th>LDL</th>
<th>HDL</th>
<th>TAG</th>
</tr>
</thead>
<tbody>
<tr>
<td>Vanhanen (1994)</td>
<td>DB, PC, R</td>
<td>3</td>
<td>HC on pravastatin therapy ≥ 1 year (n 14)</td>
<td>1·5 g sitostanol ester per d in mayonnaise (n 7)/P: rapeseed oil-based mayonnaise (n 7)</td>
<td>6 weeks</td>
<td>− 0·17 mmol/l</td>
<td>− 0·07 mmol/l</td>
<td>NS</td>
<td>NS</td>
</tr>
<tr>
<td>Richter (1996)</td>
<td>R, OL</td>
<td>1</td>
<td>HC on lovastatin therapy for 16 weeks (n 30)</td>
<td>6·0 g β-sitosterol per d in tablets (n 15)/− (n 15)</td>
<td>12 weeks</td>
<td>− 7·4 %</td>
<td>− 10·3 %</td>
<td>NS</td>
<td>NS</td>
</tr>
<tr>
<td>Blair et al. (2000)</td>
<td>DB, PC, R</td>
<td>4</td>
<td>HC on stable statin therapy ≥ 3 months (n 167)</td>
<td>5·1 g plant stanol ester per d in spread (n 83)/P: rapeseed oil-based spread (n 84)</td>
<td>8 weeks</td>
<td>− 27·4 %*</td>
<td>− 210·3 %</td>
<td>NS</td>
<td>NS</td>
</tr>
<tr>
<td>Simons (2002)</td>
<td>DB, PC, R</td>
<td>4</td>
<td>HC (n 75)§</td>
<td>Cerivastatin + 2 g plant sterol ester per d in spread (n 37)/cerivastatin + P: regular spread (n 38)</td>
<td>4 weeks</td>
<td>− 5·7 %*</td>
<td>− 6·1 %*</td>
<td>NS</td>
<td>NS</td>
</tr>
<tr>
<td>Ketomaki et al. (2005)</td>
<td>DB, R, AC, CO</td>
<td>3</td>
<td>FH on stable statin therapy ≥ 2 months (n 18)</td>
<td>2·g plant stanol ester per d and 2 g plant sterol ester per d in spread, CO (n 18)</td>
<td>4 weeks, 4 weeks (CO)</td>
<td>− 9·8 % (− 0·62 mmol/l)*</td>
<td>− 14·8 % (− 0·67 mmol/l)*</td>
<td>Stanol: NS</td>
<td>Stanol: NS</td>
</tr>
<tr>
<td>Castro Cabezas et al. (2006)</td>
<td>SB, PC, R</td>
<td>1</td>
<td>HC on stable statin therapy ≥ 6 months (n 20)</td>
<td>3 g plant stanol ester per d in spread (n 11)/P: regular spread (n 9)</td>
<td>6 weeks</td>
<td>− 6·6 % (− 0·40 mmol/l)</td>
<td>− 7·9 % (− 0·30 mmol/l)</td>
<td>Sterol: + 8·7 % (+ 0·11 mmol/l)**</td>
<td>Sterol: − 11·8 % (− 0·14 mmol/l)**</td>
</tr>
<tr>
<td>Goldkru et al. (2006)</td>
<td>DB, PC, R</td>
<td>4</td>
<td>HC on stable statin therapy ≥ 3 months (n 26)</td>
<td>1·8 g soya stanol per d in tablets (n 13)/P: starch-containing tablets (n 13)</td>
<td>6 weeks</td>
<td>− 5·7 % (− 0·31 mmol/l)</td>
<td>− 9·1 % (− 0·32 mmol/l)**</td>
<td>NS</td>
<td>NS</td>
</tr>
<tr>
<td>De Jong et al. (2007)</td>
<td>DB, PC, R</td>
<td>4</td>
<td>HC on statin therapy (n 41)</td>
<td>2·5 g plant stanol (n 15) or stanol ester per d in spread (n 15)/P: ‘light’ spread (n 11)</td>
<td>16 weeks</td>
<td>− 6·9 % (− 0·39 mmol/l)†</td>
<td>− 10·3 % (− 0·34 mmol/l)†</td>
<td>NS</td>
<td>NS</td>
</tr>
</tbody>
</table>

DB, double-blind; PC, placebo-controlled; R, randomised; HC, hypercholesterolaemic; P, placebo; OL, open-label; AC, active controlled; CO, cross-over; FH, familial hypercholesterolaemia; SB, single-blind.

* P < 0·05, ** P < 0·01, *** P < 0·001.
† Borderline significant.
‡ The net change in lipid levels was calculated by subtracting the mean change from baseline after control intervention from the mean change from baseline after plant sterol or stanol intervention, except for the study of Ketomaki et al. where the net change is the mean change from baseline after plant sterol and stanol intervention.
§ The study of Simons is a 2 × 2 factorial design study with four parallel arms. In this table the net change is calculated by subtracting the mean change from baseline after statin intervention from the mean change from baseline after combined intervention of plant sterols and stanols.
|| No significant difference between sterol and stanol esters.
Table 3. Clinical studies towards the effects on lipid levels (total, LDL- and HDL-cholesterol and TAG) of the combination therapy with statins and plant sterols or stanols: difference in effects of plant sterols or stanols between statin users and non-statin users.

<table>
<thead>
<tr>
<th>Author</th>
<th>Type of study</th>
<th>Jadad score</th>
<th>Subjects</th>
<th>Plant sterol or stanol/ control intervention</th>
<th>Study duration</th>
<th>Total cholesterol</th>
<th>LDL</th>
<th>HDL</th>
<th>TAG</th>
</tr>
</thead>
<tbody>
<tr>
<td>Gylling et al. (1997)</td>
<td>DB, R</td>
<td>2</td>
<td>CHD females on simvastatin therapy = 1 year (n=10)</td>
<td>3 g sitostanol ester per d in rapeseed oil-based spread (n=21)</td>
<td>7 weeks, 12 weeks</td>
<td>$+1.7 %$ (±0.24 mmol/l)§</td>
<td>$+2.4 %$ (±0.23 mmol/l)§</td>
<td>NS</td>
<td>NS</td>
</tr>
<tr>
<td>Vuorio et al. (2003)</td>
<td>OL</td>
<td>1</td>
<td>FH on simvastatin therapy = ≥ 8 d (n=12)</td>
<td>2.2 g stanol ester per d in rapeseed oil-based spread (n=16)</td>
<td>6 weeks, 12 weeks</td>
<td>$-1.1 %$ (±0.18 mmol/l)§§</td>
<td>$-8.5 %$ (±0.08 mmol/l)***§§</td>
<td>NS</td>
<td>NS</td>
</tr>
<tr>
<td>Simons (2002)</td>
<td>DB, PC, R</td>
<td>4</td>
<td>HC (n=76)‡</td>
<td>Cerivastatin + 2 g plant sterol ester per d in spread (n=37)/2 g plant sterol ester per d in spread + P: placebo drug (n=39)</td>
<td>4 weeks</td>
<td>$+1.8 %$</td>
<td>$+4.1 %$</td>
<td>NS</td>
<td>NS</td>
</tr>
</tbody>
</table>

DB, double-blind; R, randomised; CHD, patients with coronary artery disease; OL, open-label; FH, familial hypercholesterolaemia; PC, placebo-controlled; HC, hypercholesterolaemic; P, placebo.

** P < 0.01, *** P < 0.001.
† The study of Simons (40) is a 2 × 2 factorial design study with four parallel arms. In this table the net change is calculated by subtracting the mean change from baseline after plant sterol intervention in patients on placebo drug from the mean change from baseline after plant sterol intervention in patients on cerivastatin.
‡ The study of Simons (40) is a 2 × 2 factorial design study with four parallel arms. In this table the net change is calculated by subtracting the mean change from baseline after plant sterol intervention in patients on placebo drug from the mean change from baseline after plant sterol intervention in patients on cerivastatin.
§ In both groups significant reduction.
§§ Study of Simons (40) performed a 2 × 2 factorial design study with four parallel arms, aiming to distinguish between an additive effect and an interactive effect between plant sterol ester margarine and cerivastatin. Statistical study with four parallel treatment arms, aiming to distinguish between an additive effect and an interactive effect.

In none of the studies were adverse effects related to the use of plant sterol- or stanol-enriched products in combination with statin therapy found. However, in studies towards the effects of plant sterol or stanol-stained products in combination with statin therapy, it has been found that serum plant sterol intake (50). A synergistic effect between statins and plant sterols and stanols was effective in both statin users and non-users.

In summary it can be concluded that plant sterol and plant stanol esters are an effective approach to lower cholesterol in the presence of high cholesterol levels, which may result in an additive LDL- and total cholesterol reduction of roughly 10 (±0.41 mmol/l) and 6 (±0.35 mmol/l) respectively. Effects in FH patients on statin treatment. Cholesterol lowering is at least three times as high in FH patients as in non-FH patients. In summary it can be concluded that plant sterol and plant stanol esters are an effective approach to lower cholesterol in the presence of high cholesterol levels, which may result in an additive LDL- and total cholesterol reduction of roughly 10 (±0.41 mmol/l) and 6 (±0.35 mmol/l) respectively. Effects in FH patients on statin treatment. Cholesterol lowering is at least three times as high in FH patients as in non-FH patients. In summary it can be concluded that plant sterol and plant stanol esters are an effective approach to lower cholesterol in the presence of high cholesterol levels, which may result in an additive LDL- and total cholesterol reduction of roughly 10 (±0.41 mmol/l) and 6 (±0.35 mmol/l) respectively. Effects in FH patients on statin treatment. Cholesterol lowering is at least three times as high in FH patients as in non-FH patients.
Table 4. Clinical studies towards the effects on lipid levels (total, LDL- and HDL-cholesterol and TAG) of the combination therapy with statins and plant sterols or stanols: effects of plant sterols or stanols in combined groups of statin users and non-statin users

<table>
<thead>
<tr>
<th>Author</th>
<th>Type of study</th>
<th>Jadad score</th>
<th>Subjects</th>
<th>Plant sterol or stanol/ control intervention</th>
<th>Study duration</th>
<th>Net change in lipid levels†</th>
</tr>
</thead>
<tbody>
<tr>
<td>Neill et al. (2001)</td>
<td>DB, PC, R</td>
<td>5</td>
<td>FH on statin therapy (n 30)</td>
<td>2 g plant sterol per d in spread (n 31); P; mixed oil-based spread (n 31)</td>
<td>8 weeks</td>
<td>-7.8 % (-0.57 mmol/l)**</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td>HC (n 32)</td>
<td></td>
<td></td>
<td>-10.0 % (-0.51 mmol/l)*****</td>
</tr>
<tr>
<td>Amundsen et al. (2004)</td>
<td>OL</td>
<td>1</td>
<td>FH on statin therapy (n 19)</td>
<td>1.5 g plant sterol ester per d in spread (n 20)</td>
<td>26 weeks</td>
<td>-9.1 % (-0.53 mmol/l)**</td>
</tr>
<tr>
<td>O'Neil et al. (2004)</td>
<td>DB, PC, R</td>
<td>4</td>
<td>FH on statin therapy (n 69)</td>
<td>2 g plant sterol ester per d in spread (n 46/1.6 g plant sterol ester per d in spread + P; regular bar (n 46)</td>
<td>8 weeks</td>
<td>-11.0 % (-0.45 mmol/l)**</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td>Unaffected (n 65)</td>
<td></td>
<td></td>
<td>-10.6 % (-0.13 mmol/l)*****</td>
</tr>
</tbody>
</table>

DB, double-blind; PC, placebo-controlled; R, randomised; FH, familial hypercholesterolaemia; HC, hypercholesterolaemic; P, placebo; OL, open-label.

* P < 0.05, ** P < 0.01, *** P < 0.001.
† The net change in lipid levels was calculated by subtracting the mean change from baseline after control intervention from the mean change from baseline after plant sterol or stanol intervention in a combined group of statin users and non-statin users, except for the studies of Amundsen et al. (47) and O'Neil et al. (49) where the net change is the mean change from baseline after plant sterol or stanol intervention.
‡ No significant difference between stanol or stanol ester or between high- and low-dose stanol.

In a meta-analysis, it was estimated that 2.1 g soluble dietary fibre per day, reduces total cholesterol concentrations by 0.09 mmol/l and LDL-cholesterol concentrations by 0.07 mmol/l, respectively. Various soluble fibres, including oat products, psyllium, viscous oats, and garlic, reduce total and LDL-cholesterol concentrations.

Estimation of effects of soluble dietary fibre on lipid levels and health claims.

Soluble dietary fibre

Mechanism of action

Soluble fibre is associated with a reduced risk of CVD. In addition, soluble fibre can improve insulin sensitivity, and the increased satiety leading to lower overall energy intake.

Soluble fibre appears to be primarily responsible for the cholesterol-lowering effect of dietary fibre intake. Studies in HC patients without treatment with cardiovascular drugs showed that addition of soluble fibres (psyllium (58,59), oat products, psyllium, guar gum, and LDL-cholesterol, diet was an effective approach to reduce total cholesterol, low-density lipoprotein cholesterol, and LDL-cholesterol. These studies also showed that soluble fibre may help to reduce plasma cholesterol, but it is suggested that soluble fibre may also reduce the risk of CVD.

In addition, post-marketing surveillance of plant sterols and stanols, particularly regarding adverse effects, is required to ensure the safety of these products. Furthermore, both plant sterols and stanols are associated with reductions in plasma concentrations of LDL cholesterol, and HDL cholesterol. Reductions in all vitamins, except for vitamin C and vitamin E, can be explained by reductions in all vitamins. These reductions are associated with reductions in plasma concentrations of LDL cholesterol, and HDL cholesterol.
Results of studies exploring the combination therapy with soluble dietary fibre and statins are shown in Tables 5 and 6. All studies scored less than 4 points on the Jadad scale. Table 5 shows the effects on lipid levels of soluble fibre in statin users. The combination found that in three female HC patients, the addition of pectin daily to treatment with lovastatin resulted in an average rise in LDL-cholesterol of 42%. After the addition of pectin was stopped, levels returned to normal. Also, in an average rise in LDL-cholesterol of 42%. After the addition of pectin was stopped, levels returned to normal. Also, in an average rise in LDL-cholesterol of 42%. After the addition of pectin was stopped, levels returned to normal. Also, in an average rise in LDL-cholesterol of 42%. After the addition of pectin was stopped, levels returned to normal. Also, in an average rise in LDL-cholesterol of 42%. After

Table 5. Clinical studies towards the effects on lipid levels (total, LDL- and HDL-cholesterol and TAG) of the combination therapy with statins and soluble dietary fibre: effects of soluble dietary fibre in statin users

<table>
<thead>
<tr>
<th>Author</th>
<th>Type of study</th>
<th>Jadad score</th>
<th>Subjects</th>
<th>Soluble dietary fibre</th>
<th>Study duration</th>
<th>Total cholesterol</th>
<th>LDL</th>
<th>HDL</th>
<th>TAG</th>
</tr>
</thead>
<tbody>
<tr>
<td>Richter et al.</td>
<td>OL</td>
<td>–†</td>
<td>HC females (n 3) on lovastatin therapy</td>
<td>Pectin 15 g/d (n 3)</td>
<td>4 weeks</td>
<td>NM</td>
<td>–42%</td>
<td>NM</td>
<td>NM</td>
</tr>
<tr>
<td>(1991)</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Uusitupa et al.</td>
<td>OL</td>
<td>1</td>
<td>HC (n 31) on lovastatin therapy (80 mg/d) for 18 weeks</td>
<td>Guar gum tablets 5–20 g/d (n 31)</td>
<td>18 weeks</td>
<td>–14 % (-0·1 mmol/l)**</td>
<td>–18%</td>
<td>(-0·9 mmol/l)**</td>
<td>NS</td>
</tr>
<tr>
<td>(1991)</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

OL, open-label; HC, hypercholesterolaemic; NM, not measured or calculated. **P < 0.001.
† The net change in lipid levels is the mean change from baseline after soluble dietary fibre intervention.
‡ Jadad score was not estimated because description of the study design has not been published (study was interrupted after three patients).
Table 6. Clinical studies towards the effects on lipid levels (total, LDL- and HDL-cholesterol and TAG) of the combination therapy with statins and soluble dietary fibre: difference in effects of a statin plus soluble dietary fibre v. a statin alone

<table>
<thead>
<tr>
<th>Author</th>
<th>Type of study</th>
<th>Jadad score</th>
<th>Subjects</th>
<th>Soluble dietary fibre/control intervention</th>
<th>Study duration</th>
<th>Net change in lipid levels†</th>
</tr>
</thead>
<tbody>
<tr>
<td>Moreyra et al. (2005)</td>
<td>DB, PC, R</td>
<td>3</td>
<td>HC (n=46)</td>
<td>Simvastatin (10 mg/d) + psyllium-powder drink (15 g/d) (n=23)/simvastatin (10 mg/d) + P (n=23)</td>
<td>8 weeks</td>
<td>Total cholesterol: -3.9% (-0.24 mmol/l)<em>, LDL: -5.1% (-0.21 mmol/l)</em>, HDL: -9.1% (-0.13 mmol/l)**, TAG: +8.7% (+0.07 mmol/l)</td>
</tr>
<tr>
<td>Jayaram et al. (2007)</td>
<td>OL, R</td>
<td>2</td>
<td>HC (n=97)</td>
<td>Atorvastatin (10 mg/d) + psyllium-powder drink (11.2 g/d) (n=49)/atorvastatin (10 mg/d) (n=48)</td>
<td>12 weeks</td>
<td>Total cholesterol: -4.4% (-0.28 mmol/l)<em>, LDL: -8.6% (-0.35 mmol/l)</em>, HDL: -6.4% (-0.06 mmol/l), TAG: +0.99% (+0.06 mmol/l)</td>
</tr>
<tr>
<td>Agrawal et al. (2007)</td>
<td>OL, R</td>
<td>3</td>
<td>Unaffected males (n=24)</td>
<td>Lovastatin (20 mg/d) + psyllium-powder drink (10 g/d) (n=12)/lovastatin (20 mg/d) (n=12)</td>
<td>4 weeks</td>
<td>Total cholesterol: -6.7% (-0.3 mmol/l), LDL: -8.6% (-0.2 mmol/l), HDL: -7.1% (-0.07 mmol/l), TAG: +6.7% (+0.08 mmol/l)</td>
</tr>
</tbody>
</table>

DB, double-blind; PC, placebo-controlled; R, randomised; HC, hypercholesterolaemic; P, placebo; OL, open-label.

* P<0.05, ** P<0.01.
† The net change in lipid levels was calculated by subtracting the mean change from baseline after control intervention from the mean change from baseline after soluble dietary fibre intervention.
and a statin might be beneficial in improving the lipid profile in patients with high TAG levels. The favourable decrease in TAG levels caused by n-3 PUFA is probably due to reduced hepatic VLDL and TAG synthesis and secretion, and enhanced TAG clearance from chylomicrons and VLDL particles. Reduced synthesis might be due to increased rates of mitochondrial and/or peroxisomal β-oxidation or a decreased expression of sterol regulatory element-binding protein-1c, a transcription factor involved in the regulation of fatty acid-synthesising enzymes. Both mechanisms will result in a reduction in the availability of the substrate, i.e. fatty acids. Increased clearance is possibly caused by increased lipoprotein lipase activity due to increased PPAR-γ and/or PPAR-α gene expression. Activation of PPAR leads to increased fatty acid β-oxidation in the liver and skeletal muscle 84–86.

Other mechanisms by which n-3 PUFA may lower the risk of CHD include reductions in platelet aggregation, blood viscosity and ischaemia and their anti-thrombotic, fibrinolytic and anti-inflammatory activities. Moreover, n-3 PUFA appear to play an important role in the prevention of arrhythmias 87,88.

**Estimated effects of n-3 PUFA on lipid levels and health claims**

In a recent meta-analysis of twenty-one randomised controlled trials it was estimated that n-3 PUFA consumption resulted in significant changes in TAG of -0.31 mmol/l, in HDL-cholesterol of +0.04 mmol/l and in LDL-cholesterol of +0.16 mmol/l. There was no effect on total cholesterol 89. It has been suggested that the unfavourable increase in LDL-cholesterol is attributable to the increased conversion of VLDL to IDL and LDL, and the conversion of IDL to LDL after n-3 PUFA supplementation 90,91.

In September 2004 the FDA announced a qualified health claim for the use of food products containing both EPA and DHA n-3 PUFA for FF and DS 92. According to the FDA there is supportive, but not conclusive, scientific evidence that suggests a reduction in CHD as a result of eating food or supplements rich in n-3 PUFA. The FDA judges that n-3 PUFA generally reduce TAG and VLDL-cholesterol, and have no effect on total or HDL-cholesterol in both general and diseased populations. The EFSA has not yet evaluated health claims on n-3 PUFA and cardiovascular function.

**Effects of combination therapy with n-3 PUFA and statins**

Results of clinical studies that have investigated the combination therapy with n-3 PUFA and statins are summarised in Tables 7 and 8. Contacos et al. were the first to demonstrate a beneficial effect of the combination of n-3 PUFA and statin therapy in HC patients 93. They found that in patients randomised to either pravastatin, n-3 PUFA or placebo for 6 weeks, an additional 12 weeks of combination therapy with n-3 PUFA and pravastatin further decreased plasma TAG and LDL-cholesterol by 33% (P<0.05) and 26% (P<0.01), respectively, in patients in the placebo group, whereas in patients already on pravastatin only TAG levels were non-significantly decreased by 33% and in patients in the n-3 PUFA group only LDL-cholesterol levels were decreased by 24% (P<0.05). Total cholesterol levels showed similar changes to LDL-cholesterol after combination therapy. This study indeed showed that statins particularly lowered total and LDL-cholesterol, whereas n-3 PUFA lowered TAG and not cholesterol levels. Combination therapy reduced both cholesterol and TAG concentrations. These beneficial effects of n-3 PUFA on TAG levels have been confirmed in later studies 94–103.

Table 7 shows the results of studies examining the effects of supplementing patients on statin therapy with n-3 PUFA 93,97,98,100–103,105. All studies used EPA and/or DHA, in doses varying from 0.9 to 1.8 g/d and 0.78 to 2.16 g/d for EPA and DHA, respectively. All studies found significant reductions in TAG, ranging from 16 (or 0.44 mmol/l) to 48% (or 1.2 mmol/l), after supplementing n-3 PUFA, except one study performed by Nordøy et al. in which no TAG-lowering effect was attributable to the n-3 PUFA 105. In this study relatively low doses of n-3 PUFA (0.9 g/d EPA, 0.78 g/d DHA) were used, which could explain these results. However, one small, uncontrolled study (Jadad score = 0) in which twelve patients were supplemented with 0.9 g EPA per d and two patients with 1.8 g EPA per d showed highly significant reductions in TAG. In addition, in this study it was found that total cholesterol levels were significantly reduced and HDL-cholesterol was significantly increased after EPA supplementation 102. Most studies performed in patients on statin therapy did not find any significant changes in total, LDL- or HDL-cholesterol, although in some studies VLDL-cholesterol was decreased 93,98,101. In the COMBOS (COMbination of prescription Omega-3 with Simvastatin) study 87, administration of n-3-acid ethyl esters plus simvastatin improved, besides TAG levels, also total, HDL- and VLDL-cholesterol to a greater extent than simvastatin alone. On the unfavourable side, a trend was observed towards a greater reduction in LDL-cholesterol in the simvastatin-only group (0.7 v. −2.8%; P=0.052).

Table 8 shows the results of studies comparing the effects on lipid values of a combination therapy of a statin and n-3 PUFA v. statin treatment alone. Davidson et al. 96 found that after treating HC patients with n-3 PUFA and/or simvastatin for 12 weeks, the TAG responses were similar in the EPA/DHA-group (−25.3%) and the combined group (−28.8%), and borderline significantly lower in the simvastatin group (−18.5%), whereas decreases in non-HDL-cholesterol and increases in HDL-cholesterol were statistically significant only for the combined (non-HDL: −24.8%; HDL: +10.4%) and simvastatin group (non-HDL: −25.8%; HDL: +7.2%). All other studies found significant improvements of TAG with a combination therapy compared with the statin therapy alone 94,95,97,99,104. Study populations included, besides HC patients, renal transplant patients with persistent hypercholesterolaemia 99 and insulin-resistant obese men with dyslipidaemia 95. In this last study, also atorvastatin alone significantly decreased TAG levels. The authors suggest that the two compounds reduce TAG levels through different mechanisms. Whereas n-3 PUFA reduced the hepatic secretion of VLDL-apoB, atorvastatin enhanced the clearance of all apo B-containing lipoproteins, resulting in an additive effect 94,95. Aligeti et al. performed a retrospective cohort study in which they compared the change in plasma TAG levels between patients taking fish oil as monotherapy and patients who added fish oil to their usual lipid-lowering therapy.
Table 7. Clinical studies towards the effects on lipid levels (total, LDL- and HDL-cholesterol and TAG) of the combination therapy with statins and n-3 PUFA: effects of n-3 PUFA in statin users

<table>
<thead>
<tr>
<th>Author</th>
<th>Type of study</th>
<th>Jadad score</th>
<th>Subjects</th>
<th>n-3 PUFA/control intervention</th>
<th>Study duration</th>
<th>Total cholesterol</th>
<th>LDL</th>
<th>HDL</th>
<th>TAG</th>
</tr>
</thead>
<tbody>
<tr>
<td>Contacos et al. (1993) &lt;sup&gt;(102)&lt;/sup&gt;</td>
<td>OL</td>
<td>1</td>
<td>HC on pravastatin therapy for 6 weeks (n 9)</td>
<td>3 g PUFA oil§ per d (n 9)</td>
<td>12 weeks</td>
<td>-5.0%</td>
<td>-6.9%</td>
<td>-23.0%</td>
<td></td>
</tr>
<tr>
<td>Nordøy et al. &lt;sup&gt;(1998)&lt;/sup&gt; &lt;sup&gt;(102)&lt;/sup&gt;</td>
<td>DB, PC, R</td>
<td>4</td>
<td>HC on simvastatin for 5 or 10 weeks (n 42)</td>
<td>4 g PUFA per d in capsules‖ (n 22)/P: maize oil capsules (n 20)</td>
<td>5 weeks</td>
<td>-9.8%</td>
<td>+6.9%</td>
<td>-1.6 mmol/l</td>
<td></td>
</tr>
<tr>
<td>Nakamura et al. &lt;sup&gt;(1999)&lt;/sup&gt; &lt;sup&gt;(102)&lt;/sup&gt;</td>
<td>OL</td>
<td>0</td>
<td>HC on various statins for 30 ± 6 months (n 14)</td>
<td>0.9 - 1.8 g EPA per d in capsules (n 14)</td>
<td>3 months</td>
<td>-11%</td>
<td>NM</td>
<td>+8.9%</td>
<td></td>
</tr>
<tr>
<td>Durrington et al. &lt;sup&gt;(2001)&lt;/sup&gt; &lt;sup&gt;(102)&lt;/sup&gt;</td>
<td>DB, PC, R</td>
<td>4</td>
<td>CHD on stable statin therapy ± 3 months (n 59)</td>
<td>4 g PUFA per d in capsules‖ (n 30)/P: maize oil capsules (n 29)</td>
<td>24 weeks</td>
<td>-13.9%</td>
<td>-27.3%</td>
<td>-26.5%</td>
<td></td>
</tr>
<tr>
<td>Nordøy et al. &lt;sup&gt;(2001)&lt;/sup&gt; &lt;sup&gt;(102)&lt;/sup&gt;</td>
<td>DB, PC, R</td>
<td>4</td>
<td>HC on atorvastatin for ≥ 10 weeks (n 42)</td>
<td>2 g PUFA per d in capsules‖ (n 22)/P: maize oil capsules (n 20)</td>
<td>5 weeks</td>
<td>+4.7%</td>
<td>+5.7%</td>
<td>+6.0%</td>
<td></td>
</tr>
<tr>
<td>Hong et al. &lt;sup&gt;(2004)&lt;/sup&gt; &lt;sup&gt;(102)&lt;/sup&gt;</td>
<td>DB, PC, R</td>
<td>4</td>
<td>HC on simvastatin therapy for 6–12 weeks (n 40)</td>
<td>3 g PUFA per d in capsules‖ (n 20)/P: rapeseed oil capsules (n 20)</td>
<td>8 weeks</td>
<td>-3.7%</td>
<td>-16%</td>
<td>0.22 mmol/l</td>
<td></td>
</tr>
<tr>
<td>Meyer et al. &lt;sup&gt;(2007)&lt;/sup&gt; &lt;sup&gt;(102)&lt;/sup&gt;</td>
<td>DB, PC, R</td>
<td>2</td>
<td>HC on stable statin therapy ≥ 3 months (n 27)</td>
<td>2-16 g DHA oil per d (n 13)/P: olive oil (n 14)</td>
<td>3 weeks</td>
<td>-8.3%</td>
<td>-17.2%</td>
<td>-0.44 mmol/l</td>
<td></td>
</tr>
<tr>
<td>Davidson et al. &lt;sup&gt;(2007)&lt;/sup&gt; &lt;sup&gt;(102)&lt;/sup&gt;</td>
<td>DB, PC, R</td>
<td>5</td>
<td>HC on stable statin therapy ≥ 2 months (n 254)</td>
<td>Simvastatin + 4 g PUFA per d in capsules‖ (n 122)/simvastatin (40 mg/d) + P: vegetable oil capsules (n 132)‖</td>
<td>8 weeks</td>
<td>-3.2%</td>
<td>-24.7%</td>
<td>-0.78 mmol/l</td>
<td></td>
</tr>
</tbody>
</table>

§ EPA 67 %, DHA 33 %.
‖ EPA 45–48 %, DHA 36–39 %.

* P<0.05, ** P<0.01, *** P<0.001.
† Borderline significant.
‡ The net change in lipid levels was calculated by subtracting the mean change from baseline after control intervention from the mean change from baseline after n-3 PUFA intervention, except for the studies of Contacos et al. <sup>(102)</sup> and Nakamura et al. <sup>(102)</sup>, where the net change is the mean change from baseline after n-3 intervention.
§ EPA 67 %, DHA 33 %.
‖ EPA 45–48 %, DHA 36–39 %.
† At inclusion simvastatin replaced any previous statin.
Table 8. Clinical studies towards the effects on lipid levels (total, LDL- and HDL-cholesterol and TAG) of the combination therapy with statins and n-3 PUFA: difference in effects of a statin plus n-3 PUFA v. a statin alone

<table>
<thead>
<tr>
<th>Author et al.</th>
<th>Type of study</th>
<th>Jadad score</th>
<th>Subjects</th>
<th>n-3 PUFA/control intervention</th>
<th>Study duration</th>
<th>Total cholesterol</th>
<th>LDL</th>
<th>HDL</th>
<th>TAG</th>
</tr>
</thead>
<tbody>
<tr>
<td>Davidson et al. (1997)(98)</td>
<td>DB, PC, R</td>
<td>2</td>
<td>HC (n 19)</td>
<td>Simvastatin (10 mg/d) + 5 g PUFA per d in capsules (n 9)</td>
<td>12 weeks</td>
<td>-0.36 %</td>
<td>+1.0 %</td>
<td>+3.2 %</td>
<td>-10.3 %</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td></td>
<td>simvastatin + P (n 10)</td>
<td></td>
<td>(-0.11 mmol/l)</td>
<td>(-0.10 mmol/l)</td>
<td>(+0.05 mmol/l)</td>
<td>(-0.14 mmol/l)</td>
</tr>
<tr>
<td>Grekas et al. (2001)(99)</td>
<td>OL</td>
<td>1</td>
<td>Renal transplant HC (n 24)</td>
<td>Pravastatin (20 mg/d) (n 24) and pravastatin (20 mg/d) + 1 g PUFA oil per d (n 24)††</td>
<td>8 weeks</td>
<td>+8.3 %</td>
<td>-0.9 %</td>
<td>+4.3 %</td>
<td>-14.6 %</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td>(+0.67 mmol/l)</td>
<td>(+0.05 mmol/l)</td>
<td>(+0.05 mmol/l)</td>
<td>(-0.26 mmol/l)**</td>
</tr>
<tr>
<td>Chan et al. (2002)(100)</td>
<td>DB, PC, R</td>
<td>2</td>
<td>IR obese males (n 24)</td>
<td>Atenolol -1 + 4 g PUFA per d in capsules (n 11)</td>
<td>6 weeks</td>
<td>-0.2 %</td>
<td>+4.9 %</td>
<td>+9.6 %</td>
<td>-13.7 %</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td></td>
<td>pravastatin (20 mg/d)§</td>
<td></td>
<td>(-0.2 mmol/l)</td>
<td>(+0.08 mmol/l)</td>
<td>(+0.11 mmol/l)***</td>
<td>(-0.3 mmol/l)***</td>
</tr>
<tr>
<td>Yokoyama et al. (2007)(101)</td>
<td>OL, R</td>
<td>3</td>
<td>HC (n 18 645)</td>
<td>Pravastatin + 1.8 g EPA per d in capsules (n 9326) pravastatin + simvastatin (n 9319)</td>
<td>5 years</td>
<td>NS</td>
<td>NS</td>
<td>NS</td>
<td>NS</td>
</tr>
</tbody>
</table>

** DB, double-blind; PC, placebo-controlled; R, randomised; HC, hypercholesterolaemic; P, placebo; OL, open-label; IR, insulin-resistant.
† Borderline significant.
†† The net change in lipid levels was calculated by subtracting the mean change from baseline after control intervention from the mean change from baseline after n-3 PUFA intervention.
§ EPA 60 %, DHA 40 %.
|| EPA 45–48 %, DHA 36–39 %.
| Values are non-HDL-cholesterol.

In conclusion we can say that all clinical studies conducted in HC patients suggest that after combined intake of n-3 PUFA and statins, the lipid-lowering effect is greater when compared with the separate intake. In addition, the combined intake of n-3 PUFA and statins does not increase the risk of adverse effects. The combination therapy is also a precursor of CoQ10. 

Coenzyme Q10 is also a precursor of CoQ10.
levels (112, 113) (Fig. 2). CoQ₁₀ is known for its enzymic role in the production of energy within human cells, so CoQ₁₀ deficiency may impair muscle energy metabolism and contribute to the development of myalgia, a frequently reported adverse effect of statin treatment (114). Supplementation with CoQ₁₀ can raise the circulating levels of CoQ₁₀ and might therefore be efficient in alleviating myopathic symptoms.

**Coenzyme Q₁₀ and health claims**

Dietary supplements containing CoQ₁₀ have not been evaluated for safety and effectiveness and there are no approved health claims for the use of CoQ₁₀, neither in the USA nor in Europe.

**Effects of combination therapy with coenzyme Q₁₀ and statins**

Although studies have repeatedly demonstrated reduced levels of plasma CoQ₁₀ with statin therapy (113, 115–117) and restored levels after oral CoQ₁₀ supplementation (113, 118), large randomised controlled trials towards the impact of CoQ₁₀ supplementation on statin-induced myalgia in patients with hyperlipidaemia are lacking. Only two double-blind controlled clinical trials investigating this area have been performed. The first study, assigned a Jadad score of 2, was a pilot study in forty-four patients with self-reported myalgia. Patients were randomised to supplementation with 200 mg CoQ₁₀ per d or placebo in combination with an upward dose of simvastatin (starting dose of 10 or 20 mg/d up to 40 mg/d) for 12 weeks. Results showed no difference between the groups in severity of myalgia, in the number of patients tolerating the highest dose of simvastatin, or in the number of patients remaining on therapy (119). The second study, assigned a Jadad score of 4, was performed in thirty-two patients with myopathic symptoms taking varying doses of statins, and supplemented with CoQ₁₀ (100 mg/d) or vitamin E (400 IU/d) for 30 d (114). This study showed a significant 40 and 38% reduction in pain severity and pain interference with daily activities, respectively, in the group treated with CoQ₁₀. Vitamin E did not affect pain severity or pain interference. In this study, the benefit of CoQ₁₀ supplementation on improving pain was not stratified by statin type or dose.

In a third trial towards the effects of CoQ₁₀ supplementation on statin-induced myopathic symptoms, statin therapy was discontinued upon initial visit in all patients and no control group was included, so it is not clear what role CoQ₁₀ had in decreasing the incidence of myalgia (120).

In summary it can be concluded that although some trial evidence exists about the effectiveness of CoQ₁₀ supplementation on myopathic symptoms, it is too early to recommend its routine use in clinical practice. The only randomised controlled clinical trials investigating this area showed contrasting results and further well-performed clinical trials are needed to investigate whether CoQ₁₀ can be used to support statin therapy. Although several studies have shown that plasma CoQ₁₀ levels are decreased after statin therapy, existing evidence also suggests that skeletal muscle CoQ₁₀ levels are not affected or even increased after statin (113, 115, 116).

Alternative explanations for the myotoxic adverse effects of statins include instability of skeletal muscle cells due to reduction in cholesterol content of the membranes and inhibited production of GTP-binding proteins involved in cell growth and apoptosis. Apoptosis is a critical mechanism in the remodelling and maintenance of tissue structure and inappropriate apoptosis can produce pathological conditions (121, 122). Some of the decrease in CoQ₁₀ can probably be explained by the reduction in LDL-cholesterol levels after statin therapy, since CoQ₁₀ is transported in the LDL particle (123).

**Safety aspects of combination therapy with coenzyme Q₁₀ and statins**

CoQ₁₀ is widely recognised as safe with no reported toxicity (123). It has been shown that CoQ₁₀ supplementation (100 mg/d) in HC patients treated with atorvastatin (10 mg/d) did not have an effect on statin-induced reductions in total or LDL-cholesterol, or TAG levels (124).

**Discussion**

The main objective of this review was to present options for the support of drug therapy with FF or DS. We focused on the support of statin therapy with plant sterols and stanols, soluble fibre, n-3 PUFA or CoQ₁₀, because many subjects are treated suboptimally with statins and there are indications supporting combined use with one of these FF or DS.

There is substantial evidence that adding plant sterols or stanols to statin therapy reduces total and LDL-cholesterol, and that adding n-3 PUFA to statins reduces plasma TAG. Both combination treatments are without any changes in HDL-cholesterol. Neither supplementation of plant sterols or stanols nor supplementation with n-3 PUFA had any known clinical significant side effects, although n-3 PUFA supplementation
tended to increase LDL-cholesterol and plant sterol and stanol supplementation is associated with a reduction of β-carotene. Also the potential atherogenicity of elevated serum plant sterol concentrations needs to be further investigated.

Information about the combination therapy with either soluble dietary fibres or CoQ10 and statins is less clear. Soluble dietary fibre and statins may have additive effects on reducing total and LDL-cholesterol levels. However, also an antagonistic effect of soluble fibre supplementation on statin therapy might be expected due to a reduced drug bioavailability. Furthermore, soluble fibre supplementation has been associated with a blunting of the HDL-cholesterol-increasing effect of statins. CoQ10 may counteract the adverse myalgic effect produced by statins, but further studies are needed to confirm this hypothesis. Despite the safety and low costs of CoQ10, thus far it should not be recommended as a routine supplement with statin therapy in clinical practice. In the present review we discussed the (limited) available literature on the effectiveness of CoQ10 supplementation in reducing myopathic symptoms. Also other functional foods or dietary supplements might be helpful in reducing statin-induced side effects. Se supplementation has been suggested to reduce both statin-induced liver injury, and myotoxicity, and t-carnitine might improve statin-associated myotoxicity. However, current research is limited to cell-culture and animal experiments, and human studies should be performed to assess the potential protective effects of these compounds in man. In the present review we have limited our literature search to human studies.

In conclusion it can be stated that using FF or DS might be an effective and safe approach to support drug therapy, especially when drugs alone are insufficient to achieve desirable effects on risk factors or when drug use is associated with side effects. In our example, FF or DS fortified with plant sterols or stanols or n-3 PUFAs are a good option for supporting statin therapy. However, every combination of a drug and a FF or DS has to be investigated separately to draw conclusions about the type of effect: additive, synergistic, antagonistic or no effect. In our example of statin therapy, it is possible that various statins have different effects when combined to FF or DS, as statins vary in intestinal absorption and bioavailability. Also studies towards the effects of genetic polymorphisms are warranted as indicated by, for example, the association between variants in SLCO1B1 (solute carrier organic anion transporter family, member 1B1) and increased risk of statin-induced myopathy, the association between ABCA1 expression and cholesterol absorption after intake of plant stanols, and the association between polymorphisms in the fatty acid desaturase (FADS) genes and fatty acid concentrations in plasma and erythrocyte membranes.

More research is needed towards the effect that a FF or DS has on side effects caused by drugs, and whether side effects can be reduced by replacing some dose of the drugs with FF or DS, without altering the effects on risk factors. Post-marketing surveillance studies are required to assess the long-term safety of the combination therapies and the safety in specific risk groups; clinical trials do often not attain adequate power for evaluating rare events and interactions. Moreover, the effectiveness of the combination therapies under customary conditions should be addressed as adherence to drugs is known to be suboptimal and recommended doses of FF and DS might not be consumed.

Acknowledgements

The present review was funded by a grant from the National Institute for Public Health and the Environment (RIVM).

It was written by S. E., with O. K., J. G., H. V., H. vK., H. vL. and C. R. all providing comments. All authors reviewed the contents of the paper, approved its contents and validated the accuracy of the data.

The division of Pharmacoepidemiology and Pharmacotherapy employing authors S. E. and O. K. received unrestricted funding for pharmacoepidemiological research from GlaxoSmithKline, Novo Nordisk, the private–public funded Top Institute Pharma (www.tipharma.nl, including co-funding from universities, government and industry), the Dutch Medicines Evaluation Board and the Dutch Ministry of Health.

J. G., H. V., H. vK., H. vL. and C. R. have no conflicts of interest to disclose.

Note added to proof

Since the paper was accepted, the European Commission and member states have adopted and authorised the health claims for plant sterols and stanols. The European Food Safety Authority (EFSA) has evaluated and approved health claims for oat and barley β-glucans.

References


