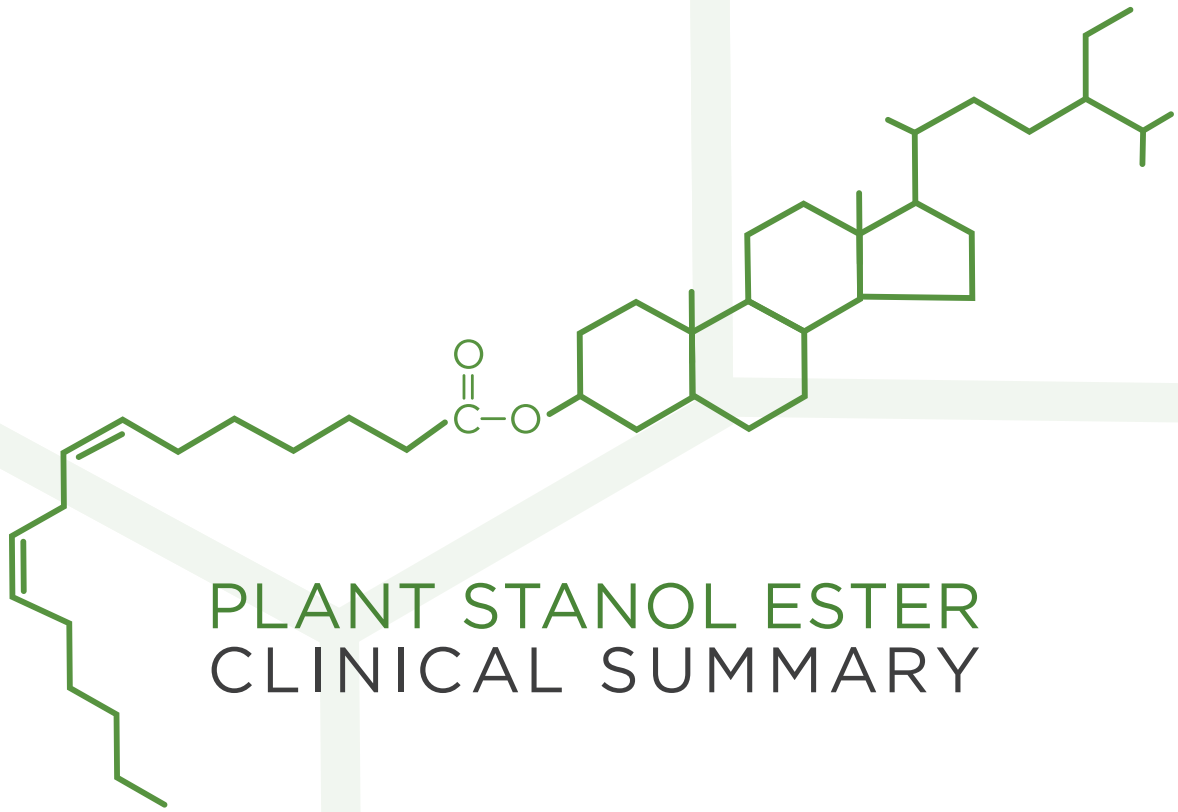

PLANT STANOL ESTER CLINICAL SUMMARY

Benecol®
PROVEN TO LOWER CHOLESTEROL

Plant stanol ester has been shown to lower cholesterol. High cholesterol is a risk factor in the development of coronary heart disease. A daily intake of 1.5–2.4 g plant stanols lowers cholesterol by 7–10% in 2 to 3 weeks. The beneficial effect is obtained with a daily intake of 1.5–3.0 g plant stanols.

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Contents

Introduction

Maintaining a healthy blood cholesterol level is important to support heart wellbeing and reduce the risk of heart disease.

Functional foods with added plant stanol ester provide an effective way to lower 'bad' LDL cholesterol (LDL-C) as part of a healthy cholesterol-lowering diet.

This *Plant Stanol Ester Clinical Summary* outlines the clinical data around plant stanol ester, the active cholesterol-lowering ingredient in Benecol® functional foods.

The relevance of lowering LDL cholesterol

More people die from cardiovascular disease (CVD) worldwide than from any other cause.[1] Of which, coronary heart disease (CHD) is the biggest culprit, due to the build-up of fatty deposits in the blood vessels (atherosclerosis) causing blockages and preventing blood supply to the heart or brain (heart attack or stroke).[2] The presence of CHD is attributable to a combination of risk factors including increasing age, male gender (at an earlier age), genetic factors, smoking, poor diet and physical inactivity. Some of these factors can be managed, while others are not modifiable. The good news is that 80% of premature heart attacks and strokes are preventable with careful management of modifiable risk factors.[3]

Elevated blood cholesterol, or hyperlipidaemia, is a major modifiable risk factor for CHD and widely studied. Low-density lipoproteins (LDL-C) in particular, have been directly implicated in the development of atherosclerotic CVD (ASCVD).[4] Millions of people around the world live with elevated cholesterol, and according to the World Health Organization a third of global CHD is attributable to high cholesterol alone.[5] It is estimated that raised cholesterol globally causes 2.6 million deaths and around 30 million disability-adjusted life years.[5]

It is well established that lowering LDL-C decreases the number and risk of coronary events.[6–8] A large number of epidemiological studies and clinical trials suggest that for every 10 mg/dL (0.26 mmol/L) decrease in LDL-C, the relative risk for CHD is reduced by approximately 10%.[4] This reduced risk of coronary events is proportional to the reduction in LDL-C and thus used as a basis for preventive policies.[9] As a result, both primary prevention of heart attacks and strokes, as well as secondary prevention of recurrent events, involve lifestyle modification and drug therapies to manage dyslipidaemia and in particular to reduce LDL-C.[10]

LDL cholesterol: the earlier, the better; the lower, the better

There is good evidence to indicate that the process of atherosclerosis can manifest before there are any apparent risk factors. In 2017, Fernández-Friera *et al.* studied 1779 subjects who did not exhibit CVD risk factors and found that plaque or coronary artery calcification were present in 49.7% of these subjects.[11] The results demonstrate an independent and direct link between LDL-C levels and atherosclerotic burden (Fig 1). The findings suggest that many middle-aged individuals with an LDL-C concentration of greater than 50–60 mg/dL (1.3–1.6 mmol/L) are likely to have clinically manifested atherosclerosis.[11] These concentrations are currently considered as normal, according to clinical thresholds, which supports the cause for more effective LDL-C lowering, even in individuals without conventional cardiovascular risk factors.

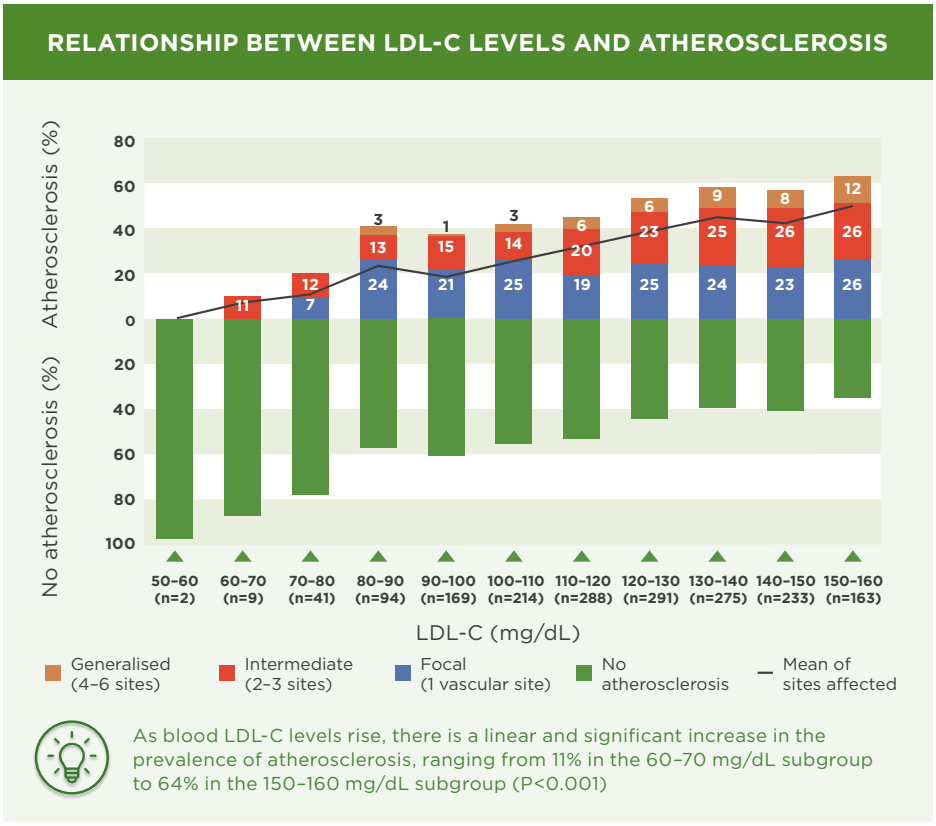


Fig 1.
Linear relationship between blood LDL-C and presence of atherosclerosis (P<0.001). Adapted from Fernández-Friera et al. (2017).[11]

LDL-C=low-density lipoprotein cholesterol.

A series of meta-analyses by Ference *et al*. have elegantly shown that a life-long low LDL-C level reduces the risk of CHD substantially more than lowering LDL-C later in life.[12] Long-term exposure to lower blood LDL-C was associated with a 54.5% reduction in the risk of CHD for each mmol/L lower LDL-C.[12] This represents a 3-fold greater reduction in the risk of CHD per unit lower LDL-C than that observed during treatment with a statin, which is started later in life. The authors conclude that a prolonged exposure to lower LDL-C beginning early in life is associated with a substantially greater reduction in the risk of CHD than the current practice of lowering LDL-C only later in life.[12] Although it has convincingly been shown that cholesterol lowering pays off in older age, this study provides strong evidence for a prophylactic approach to lower the risk of CHD by lowering LDL-C earlier in life, for example via lifestyle adjustment. The existing data therefore support the statement regarding *LDL-C: the earlier, the better; the lower, the better*.

During the 85th European Atherosclerosis Society (EAS) congress in Prague, the EAS published a consensus statement confirming the causal role of LDL-C in the development of ASCVD.[4] The consensus statement is based on a meta-analysis of more than 200 prospective cohort studies, Mendelian randomisation studies and randomised controlled trials, including in total over 2 million participants, more than 20 million person-years of follow-up, and over 150 000 cardiovascular events. The main conclusion presented in the consensus statement is: "Consistent evidence from numerous and multiple different types of clinical and genetic studies unequivocally establishes that LDL causes ASCVD."[4]

The EAS consensus statement discusses compelling evidence that the causal effect of LDL-C on ASCVD is largely independent of the mechanism by which LDL-C is 'lowered'. It therefore confirms that LDL-C is not only a biomarker, but a causal factor for ASCVD. The consensus statement also states that the effect of LDL-C is cumulative, meaning that the higher the LDL-C is and the longer a person has elevated LDL-C, the higher the risk of ASCVD.[4] Thus, lowering LDL-C early in life provides a major opportunity to reduce the lifetime risk of a cardiovascular event.

Even small LDL cholesterol reductions are beneficial

The well established linear relationship between LDL-C and relative risk of CHD has been consistently supported by clinical, epidemiological and genetic studies (Fig 2).[4,9,13] The relationship suggests that even small LDL-C reductions are worthwhile to minimise risk of disease and that an additional reduction in CHD risk is obtained when LDL-C is reduced below the typically recommended upper LDL-C concentration of 110 mg/dL (3.0 mmol/L).

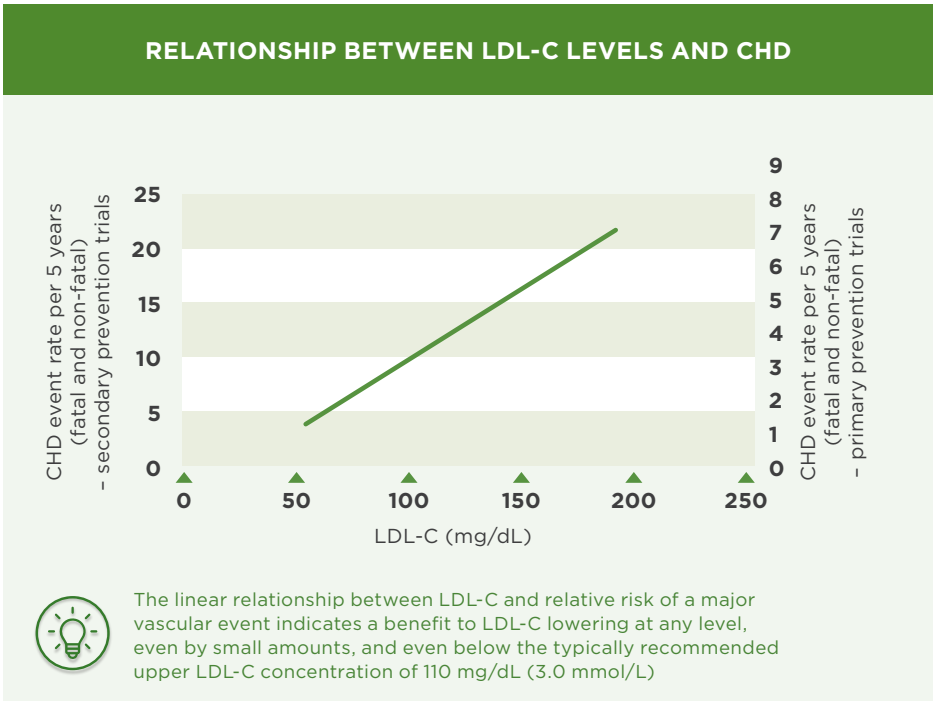


Fig 2. Linear association between LDL-C level and absolute CHD event rate based on the extensive clinical evidence. Trendlines for primary and secondary prevention associations are virtually superimposable. Adapted from Ference et al. 2018.[4]

CHD=coronary heart disease; LDL-C=low-density lipoprotein cholesterol.

Findings from the Oslo Diet-Heart Study further support the benefit of moderate LDL-C lowering by dietary means.[14] Survivors of a myocardial infarction were randomly assigned to either a cholesterol-lowering dietary intervention or control group. After 5 years of follow-up the intervention group had a mean decrease in total cholesterol of 17.6%, compared with only 3.7% in the control group.

With a starting mean total cholesterol in both groups of 296 mg/dL (7.65 mmol/L), the mean total cholesterol concentration at the end of the 5-year period was 244 mg/dL (6.31 mmol/L) in the intervention group and 285 mg/dL (7.37 mmol/L) in the control group, both higher than the normal upper level of total cholesterol officially recommended (200 mg/dL [5.17 mmol/L]). After 11 years, incidence of myocardial infarction mortality was significantly reduced in the diet group compared with the control group (32 vs 57; P=0.004) and there were also fewer coronary deaths (fatal myocardial infarction and sudden death): 79 in the diet group vs 94 in the control group (P=0.097).[14] Thus, the Oslo Diet-Heart Study clearly shows that you do not need to reach cholesterol concentrations below the upper recommended levels to obtain the benefit from cholesterol lowering.

A panel of the International Atherosclerosis Society (IAS) highlight the importance of lifestyle changes and urges lifestyle changes to be implemented as part of the primary prevention.[9] The IAS panel favoured the use of lifestyle intervention to reverse unhealthy life habits and stated that drugs should be reserved for patients at greater risk.[9]

The Myocardial Infarction Genetics Consortium Investigators found that gene mutations causing loss of function to a dietary cholesterol transporter in the gut were associated with both reduced LDL-C levels and a reduced risk of CHD.[15] Carriers of these loss-of-function mutations had significantly lower levels of total cholesterol and LDL-C (mean adjusted difference, −12 mg/dL [0.31 mmol/L]; P=0.04), which in turn was associated with a 53% reduction in the risk of CHD.[15] The lower level of cholesterol observed in carriers of these mutations correspond to cholesterol reductions that can be achieved using dietary modifications in a non-carrier, meaning the findings of this study strongly indicate that this level of LDL-C lowering is large enough to result in risk reduction of CHD, the extent of which is dependent on how early in life the LDL-C lowering is achieved.

Reducing LDL cholesterol can have a clinically relevant treatment effect

To determine the clinical benefit of reducing LDL-C, investigators have measured the impact of LDL-C level on rate of vascular events. The Cholesterol Treatment Trialists' (CCT) Collaborators conducted a meta-analysis of individual data from 27 randomised trials studying the effects of lowering LDL-C with statin therapy in people at low risk of vascular disease.[13] The findings concluded a reduction of LDL-C with a statin reduced the risk of major vascular events (rate ratio 0.79, 95% CI 0.77–0.81, per 1.0 mmol/L reduction), largely irrespective of age, sex, baseline LDL-C or previous vascular disease, and of vascular and all-cause mortality.[13]

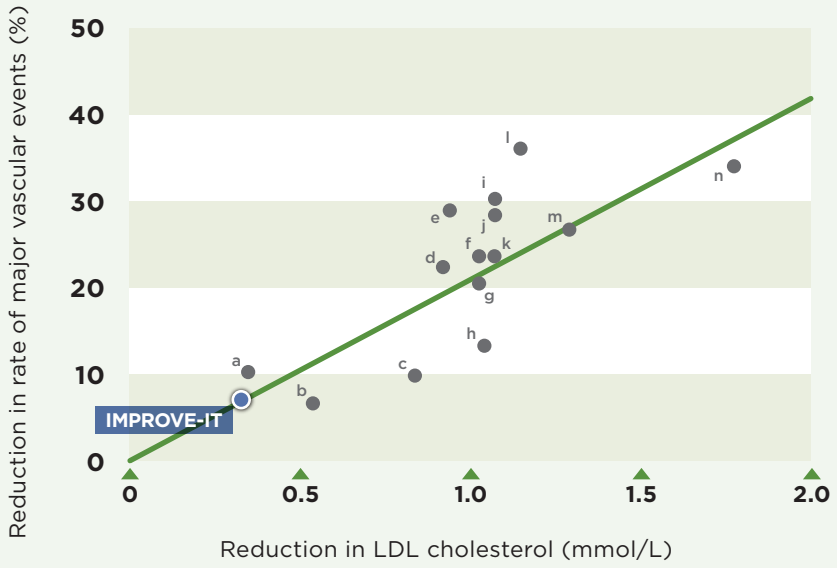
More recently, the IMPROVE-IT study investigated the effect of adding ezetimibe to statin therapy on the rate of cardiovascular events.[8] Ezetimibe is a drug that lowers blood LDL-C by reducing cholesterol absorption, with 10 mg/day reducing LDL-C on average by 18%. As with plant stanol ester, ezetimibe reduces LDL-C by partly blocking the absorption of dietary and biliary cholesterol from the digestive tract. When added to statin therapy, ezetimibe resulted in incremental lowering of LDL-C and improved cardiovascular outcomes.[8]

The IMPROVE-IT study provides strong evidence that lowering LDL-C through the reduction of cholesterol absorption from the digestive tract results in an expected reduction in the risk of major vascular events.[8] It indicates that the linear relationship between the reduction in absolute concentrations of LDL-C and the reduction in fatal and non-fatal vascular events, as established by the CTT Collaborators,[13] can be used to estimate the expected reduction in the rate of major vascular events due to LDL-C lowering, in the case of the IMPROVE-IT study, by reduction of cholesterol absorption (Fig 3).

Fig 3. Relationship between reduction in LDL-C and cardiovascular event rate. Adapted from Cannon et al. 2015.[8]

LDL-C=low-density lipoprotein cholesterol.

LOWERING LDL-C REDUCES THE RISK OF VASCULAR EVENTS



There is a linear relationship between the magnitude of LDL-C reduction and the risk of major cardiovascular events

a: *Gruppo Italiano per lo Studio della Sopravvivenza nell'Infarto Miocardico (GISSI Prevenzione);* ***b:*** *Antihypertensive and Lipid-Lowering Treatment to Prevent Heart Attack Trial–Lipid Lowering Trial (ALLHAT-LLT);* ***c:*** *Assessment of Lescol in Renal Transplantation (ALERT);* ***d:*** *Lescol Intervention Prevention Study (LIPS);* ***e:*** *Air Force/Texas Coronary Atherosclerosis Prevention Study (AFCAPS/TexCAPS);* ***f:*** *Cholesterol and Recurrent Events (CARE);* ***g:*** *Long-term Intervention with Pravastatin in Ischaemic Disease (LIPID);* ***h:*** *Prospective Study of Pravastatin in the Elderly at Risk (PROSPER);* ***i:*** *Anglo-Scandinavian Cardiac Outcomes Trial–Lipid Lowering Arm (ASCOT-LLA);* ***j:*** *West of Scotland Coronary Prevention Study (WOSCOPS);* ***k:*** *Post–Coronary Artery Bypass Graft (Post CABG);* ***l:*** *Collaborative Atorvastatin Diabetes Study (CARDS);* ***m:*** *Heart Protection Study (HPS);* ***n:*** *Scandinavian Simvastatin Survival Study (4S). Adapted from Cannon et al. 2015.[8]*

Summary

- High blood cholesterol, or hyperlipidaemia, is a major modifiable risk factor for CHD; one of the major causes of death globally
- Experts agree that elevated plasma LDL-C is causal in the development of ASCVD
- It has been estimated that for every 10 mg/dL (0.26 mmol/L) decrease in LDL-C, the relative risk for CHD is reduced by approximately 10%
- Strong evidence indicates that lowering LDL cholesterol through the reduction of cholesterol absorption from the digestive tract results in an expected reduction in the risk of major vascular events

Plant stanol ester: what it is and how it lowers LDL cholesterol

Plant stanols and plant sterols are plant-based compounds that lower blood cholesterol. Their benefit was discovered in the 1950s,[16] but it was not until several decades later when researcher Ingmar Wester developed a method for incorporating plant stanols (in the form of plant stanol esters) into food products. This innovation allowed for plant stanols to be clinically studied, and during the early 1990s the cholesterol-lowering effect of plant stanol ester was verified.

Plant stanols are structural components of plant cells and naturally found in foods. The most common dietary sources of plant stanols are cereals, mainly wheat and rye.[17,18] Daily intake of plant stanols from a normal diet is about 20–30 mg/d.[19,20] Plant stanols structurally resemble cholesterol (Fig 4), which is why they can interfere with cholesterol absorption in the small intestine. Reduced absorption of cholesterol results in reduced serum total cholesterol and LDL-C levels, yet the average diet does not contain enough plant stanols to effectively lower serum cholesterol.

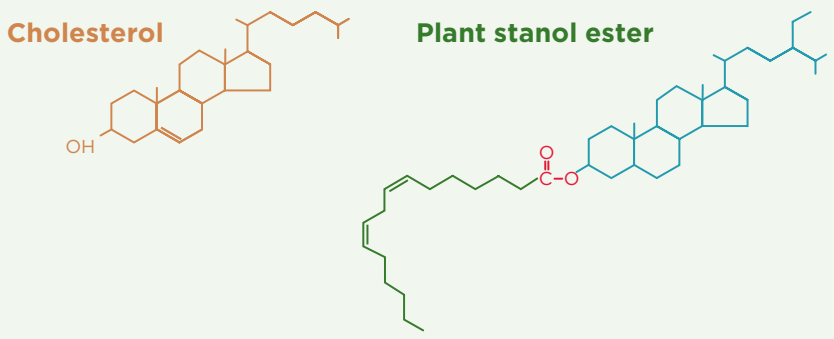
There are technical limitations related to the use of plant stanols in free form in foods, as they tend to form crystals that will not lower cholesterol optimally, and feel granular in the mouth. To ensure an adequate intake of plant stanols in a palatable form, a process to esterify plant stanols with vegetable oil fatty acids was developed. Adding esterified plant stanols to a food product does not affect its taste or mouthfeel, and most importantly, esterified plant stanols lower cholesterol effectively.[21,22]

Plant stanol ester cholesterol-lowering efficacy

Plant stanol ester lowers blood cholesterol by partly inhibiting the absorption of cholesterol in the small intestine. As soon as the plant stanol ester reaches the small intestine it is rapidly hydrolysed to free plant stanols and fatty acids.[23] Free plant stanols can then interfere with the solubilisation of cholesterol, i.e. the incorporation of cholesterol into mixed micelles (Fig 5).[24] This happens because of the structural similarity of plant stanols and cholesterol (Fig 4). Solubilisation of cholesterol into mixed micelles is a necessary part of cholesterol uptake; the less cholesterol is solubilised into mixed micelles, the more cholesterol is excreted from the body.

Fig 4. *Plant stanol ester is formed when a plant stanol molecule (blue) is joined to a vegetable oil fatty acid (green) by an ester bond (red). Plant stanol molecule closely resembles cholesterol (orange).*

THE MOLECULAR STRUCTURES OF CHOLESTEROL AND PLANT STANOL ESTER



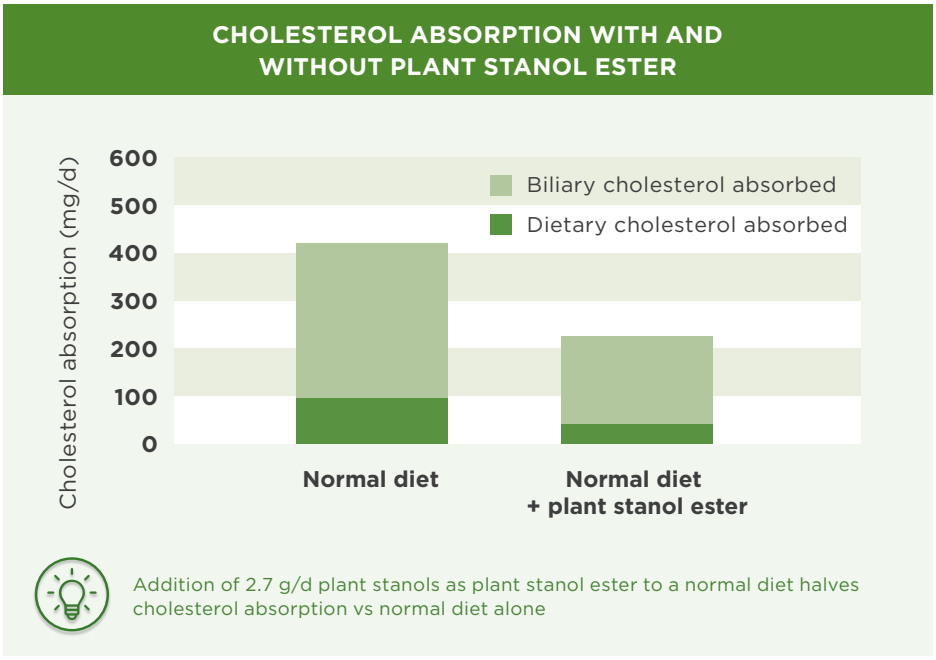
Plant stanols structurally resemble cholesterol

Fig 5.
Simplified cross section of small intestine. Mixed micelles carry cholesterol and other fat-soluble substances to the intestinal wall to be absorbed. Due to structural similarity, plant stanols can partly replace cholesterol from the micelles, disturbing its absorption. Adapted from Gylling et al. 2014.[24]

Plant stanols may also influence cholesterol absorption in the enterocyte, or in the brush border membrane of the enterocyte, but these mechanisms are yet to be fully understood.[25,26]

Consuming plant stanol ester inhibits the absorption of both dietary cholesterol (the cholesterol coming to the digestive tract via food) and biliary cholesterol (the cholesterol coming to the digestive tract with the bile solution).[27] Cholesterol absorption efficiency is reduced by about 50% with 2 g/d plant stanols (Fig 6).[27,28] Consuming plant stanols with a meal ensures optimal reduction of cholesterol absorption, because bile is excreted into the digestive tract following a meal. Plant stanol ester does not have to be consumed with every meal, however, and consumption once a day is enough for full effect.[29] This finding supports the notion that the cholesterol-lowering effect of plant stanols is not only limited to changes in micellar composition; plant stanols may also affect cholesterol trafficking in enterocytes through a currently unknown mechanism.[25,26]

Fig 6. Plant stanols reduce the absorption of both dietary and biliary cholesterol. Adapted from Gylling et al. 1997.[27]



The reduced cholesterol absorption achieved with plant stanol ester leads to significantly reduced levels of serum total cholesterol and LDL-C, with no effect on HDL cholesterol.[e.g.22,24,27,30,31] Lowering LDL-C with plant stanols does not affect the mean size of the LDL particles.[32]

Plant stanol ester is safe and well tolerated

Plant stanols are effectively eliminated from the body in an unchanged form: when foods with added plant stanols are consumed, only about 0.05–0.2% of plant stanols are absorbed.[33,34] On a normal diet, serum plant stanol concentration is approximately 10–15 µg/dL.[35] A daily intake of 2 g plant stanols (as plant stanol ester) increases serum plant stanol concentrations to 20–30 µg/dL.[35] Even if daily intake is higher (up to 9 g/d), serum levels of plant stanols remain at low levels.[36,37]

Clinical safety markers and adverse effects have been monitored in all plant stanol ester intervention studies and no safety issues have been detected, even in long-term use.[38–40] Plant stanol ester consumption has also shown to be safe and well tolerated for mothers and their babies during pregnancy and breastfeeding.[41]

Fat-soluble vitamins are also absorbed via micelles, so one question has been raised as to whether plant stanol ester consumption disturbs their uptake – but plasma levels of fat-soluble vitamins A and D are not affected by consumption of plant stanol ester.[30,35,36,42] A small decrease in plasma ß-carotene concentration has been noted in some,[29,30,42,43] but not all studies.[44] However, the dose of plant stanols (up to 9 g/d) or the duration of the intervention did not account for the observed differences, and plasma ß-carotene concentrations remained within reference values.[29,36,37,45–47] This suggests that other factors, such as diet and seasonal changes, may be more important in explaining the variation in plasma ß-carotene levels.[45] The moderate decrease in plasma ß-carotene levels related to plant stanol ester consumption can be prevented by consuming fruit and vegetables according to dietary guidelines.[48]

Summary

- Plant stanols are plant-based compounds found naturally in foods, which when added in the form of plant stanol esters to cholesterol-lowering functional foods can provide a solution to help manage blood lipids
- Plant stanols structurally resemble cholesterol, causing them to interfere with cholesterol absorption in the small intestine resulting in reduced absorption of cholesterol and reduced serum total cholesterol and LDL-C levels
- Consuming sufficient quantities of plant stanol ester with a meal ensures optimal reduction of cholesterol absorption

Robust and sustainable cholesterol reduction

To date, over 80 clinical studies have been published exploring the efficacy of plant stanol ester in different usage situations. The main finding is that whatever the circumstances are, a daily intake of 1.5–3.0 g of plant stanols (as plant stanol ester) reduces serum total cholesterol and LDL-C dose-dependently from 7 to 12.5%, on average, with no effect on HDL cholesterol (Fig 7).[49–52]

Reducing cholesterol with plant stanol ester is fast. There is a measurable reduction in serum LDL-C within the first week of continuous plant stanol ester use,[53,54] and full reduction is typically achieved within 2–3 weeks.[47,48,55]

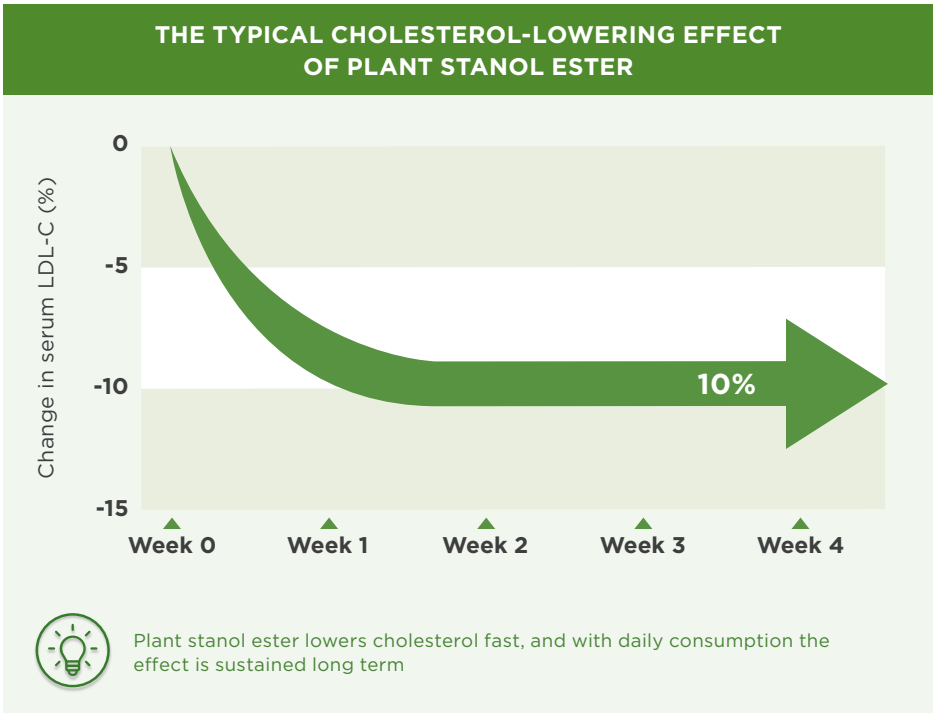


Fig 7. *The cholesterol-lowering effect of plant stanol ester is fast, and the effect is sustained with sufficient daily consumption. Magnitude of reduction depends on the daily plant stanol dose. Adapted from EFSA Panel on Dietetic Products, Nutrition and Allergies. 2012.*[52]

LDL-C=low-density lipoprotein cholesterol.

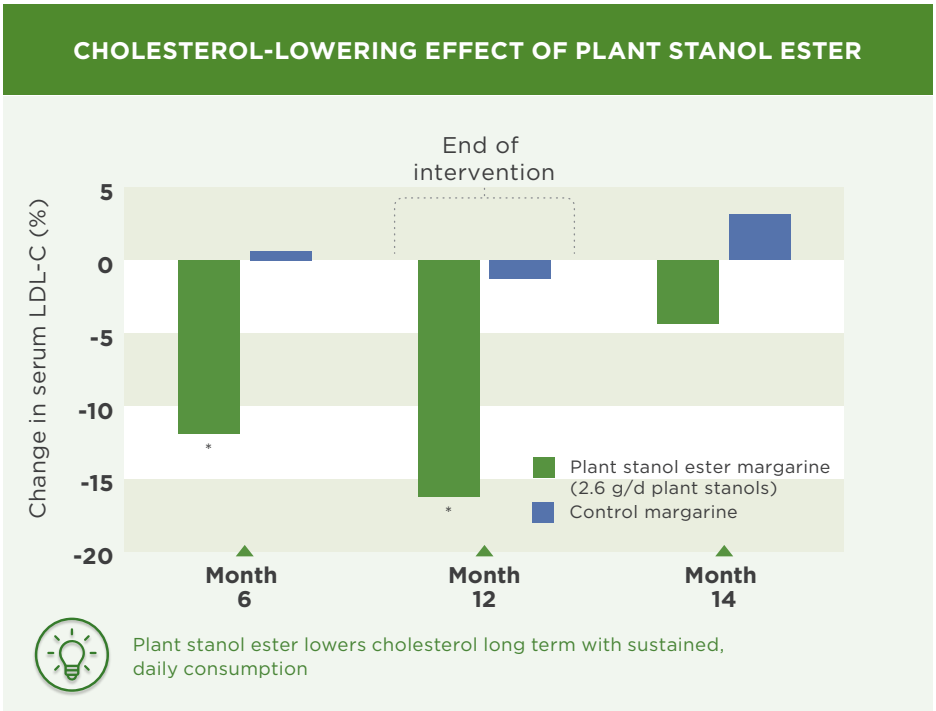
Cholesterol reduction with plant stanol ester can also be sustained with daily intake. The landmark study by Miettinen *et al*. in 1995 showed that the cholesterol-lowering effect of plant stanol ester was sustained throughout the 12-month intervention period.[22] After the intervention period ended and plant stanol ester consumption was ceased, however, LDL-C quickly rose back to starting levels, suggesting that plant stanol ester needs to be consumed on a daily basis to gain long-term benefits (Fig 8).

The sustained cholesterol-lowering effect of plant stanol ester has been confirmed in other long-term studies (12–18 months duration).[56–58] The sustained effect has also been shown in conjunction with statin treatment,[57] both plant stanol ester containing margarine,[22,56,57] and single-serving yogurt drinks.[58]

It is not necessary to consume plant stanol ester at every meal to lower cholesterol efficiently.[29] As long as plant stanol ester consumption is sufficient and daily, the efficacy is consistent – independent of whether the daily dose is consumed at one occasion or divided over several meals.[29]

Fig 8. *Cholesterol-lowering effect of plant stanol ester enriched margarine. Reduction in LDL-C was sustained throughout the study, but as the use of the margarine was ceased after 12 months, the levels rose again close to the starting values. *P<0.001 vs. control. Adapted from Miettinen et al. 1995.[22]*

LDL-C=low-density lipoprotein cholesterol.



How much plant stanol ester is enough?

The effect of plant stanol ester is dose dependent. Studies from the 1990s confirmed that a dose of around 1.5–3 g/d plant stanols as plant stanol ester was optimal to achieve most of the cholesterol-lowering potential of plant stanols (Fig 9).[22,59,60] As higher doses were studied, however, efficacy was shown to improve gradually by increasing the dose up to an intake of 9 g/d.[36,37,51] For a clinical benefit, ensuring an adequate daily intake of plant stanols is important: if the daily intake is low, optimal cholesterol-lowering effect will not be achieved.

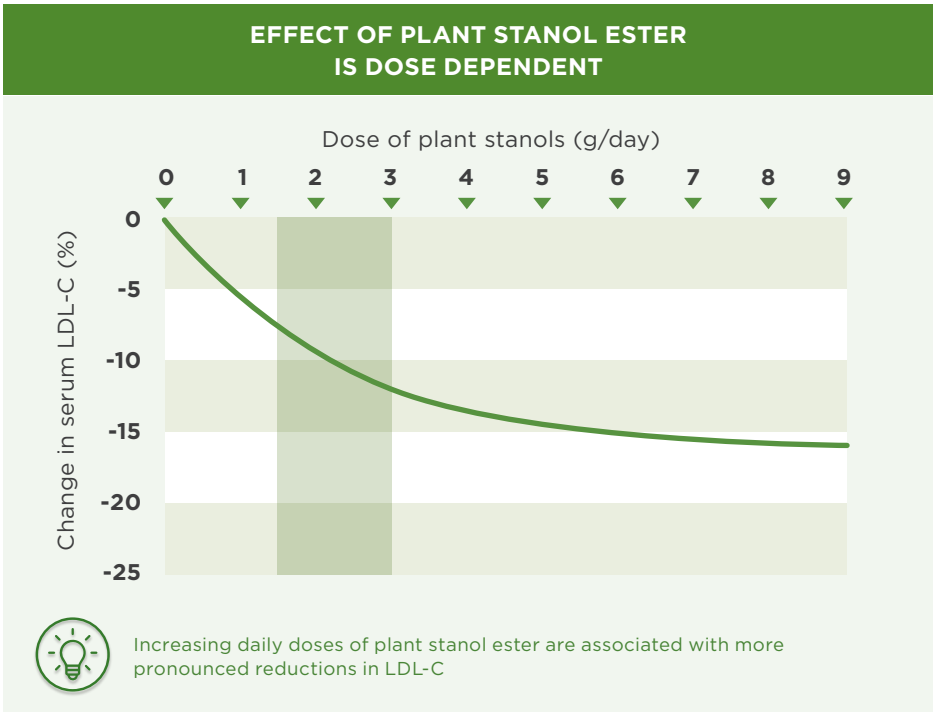


Fig 9.
For best benefit an intake of around 1.5–3 g plant stanols as plant stanol ester per day is recommendable. If intake is low or irregular the cholesterol-lowering benefit may not be achieved. Higher daily dose gives a better result. Adapted from Musa-Veloso et al. 2011.[51]

LDL-C=low-density lipoprotein cholesterol.

Effective in any type of food

Plant stanol ester needs to be consumed with a meal.[51] This is because lipid-digesting enzymes excreted when a meal is consumed are needed to cleave the plant stanol from the fatty acid, which happens rapidly and allows the plant stanols to work. All plant stanol ester-containing foods therefore need to be consumed with a meal to work, with the exception of cereal bars which are considered a meal themselves.

It is easiest to add plant stanol ester into the fat-phase of a food. In the first clinical studies on plant stanol ester, the ingredient was added to mayonnaise.[59–62] However, margarine was better suited to Finnish eating habits, which is why the first Benecol product launched in Finland in 1995 was a margarine. As a result, the vast majority of the clinical studies have assessed plant stanol ester incorporated into spreads.[21,22,27–31,35–37,43,48,53–57,63–96]

To date, several product formats have been shown to be suitable matrices for plant stanol ester. Food matrices studied include dairy products like butter,[97] low-fat hard cheese,[98] yogurt,[47,99–103] yogurt drinks,[58,100,104–107] and milk;[100] non-dairy soy-based drinks[108,109] soy-based yogurts;[37] instant coffee mix;[110] cereal products such as biscuits,[111] cereal bars,[85] cakes and cookies,[29] muesli,[112] and pasta.[105] Also the convenience food format has been tested with a meat-based ready-made low-fat meal.[105] Outside the traditional food category the efficacy of plant stanol ester in food supplement form has been tested with capsules[113,114] and chewy pastilles.[115,116]

Plant stanol ester has been shown to lower cholesterol. High cholesterol is a risk factor in the development of coronary heart disease. A daily intake of 1.5–2.4 g plant stanols lowers cholesterol by 7–10% in 2 to 3 weeks. The beneficial effect is obtained with a daily intake of 1.5–3.0 g plant stanols.

Summary

- Functional foods with added plant stanol ester provide a safe and effective way to lower cholesterol as part of a cholesterol-lowering diet
- The cholesterol-lowering effect of the plant stanols in Benecol have been demonstrated in over 80 published clinical studies
- Research has shown that in just 2–3 weeks, a daily intake of 2 grams of plant stanols lowers LDL-C by an average of 10%
- This effect is sustained provided plant stanols are consumed in the recommended quantities as part of daily main meals

Effective cholesterol reduction in different subject groups

Approximately half of the adult population in developed countries have elevated cholesterol values.[5] Plant stanol ester has been shown to be equally effective in all different population and patient groups, regardless of age, sex, genetics or dietary preferences.

The efficacy of plant stanol ester has been studied in hypercholesterolaemic individuals with different genetic backgrounds all over the world. Studies have been made in different cultures, each with unique food preferences and dietary patterns. The cholesterol-lowering efficacy of plant stanol ester is proven to be universal in all populations studied, ranging from Finland,[e.g.22,36] Sweden,[92,108] the United Kingdom,[85] the Netherlands,[e.g.37,47] Germany,[105] Spain,[58,106] Greece,[86] Turkey,[99] the United States,[30] Canada,[114] Colombia,[107] Japan,[90] Korea,[101] Thailand,[109–111] Australia,[103] to Indonesia.[117]

The relative cholesterol-lowering effect of plant stanol ester is independent of baseline cholesterol values. Subjects with normal or only mildly elevated LDL-C show similar relative LDL-C reduction (of approximately 7–10%)[74,79,101] as hypercholesterolaemic subjects.

Maintaining low cholesterol levels throughout life is the most effective way to prevent coronary events,[12] so cholesterol-lowering dietary tools should be utilised as early as possible; in childhood if needed.[118] Plant stanol ester is an effective and safe tool for cholesterol lowering in both hypercholesterolaemic,[71,83,119] and healthy children,[79,84] shown in children from age 2 years upwards.

Clinical studies have shown that the individual response to plant stanol ester varies. It is not clear whether this is a real phenomenon or a chance finding caused, for example, by normal cholesterol fluctuation or insufficient use of the products. It has been suggested that the serum cholesterol-lowering effect of plant stanol ester might be stronger in people with effective cholesterol absorption, rather than effective synthesis of cholesterol within the body.[120]
Yet, not even studies where the efficacy of cholesterol absorption has been measured at baseline have given any clear answers to this question.[27,68,81]

Primary prevention

Diabetes and metabolic syndrome

Diabetes is an independent risk factor for CVD; thus, managing other CVD risk factors, including serum total cholesterol and LDL-C, is considered essential in both type 1 and type 2 diabetes. Plant stanol ester is a useful strategy for LDL-C reduction in people with type 1 diabetes,[89] also after statin medication has been initiated,[87] as well as in people with type 2 diabetes.[21,28,121]

Metabolic syndrome is a state characterised by an accumulation of risk factors that may lead to development of type 2 diabetes or CVD. Plant stanol ester alone or combined with a low-dose statin, lowered serum non-HDL cholesterol and triacylglycerol in people with metabolic syndrome.[104]

Familial hypercholesterolaemia

Individuals with familial hypercholesterolemia (FH) suffer from genetically elevated LDL-C levels from birth. If left untreated, the risk of premature CVD and mortality is significantly increased in these individuals. A good response to plant stanol ester has been noted in adults both with and without statin medication,[83,91,94] as well as in children with FH.[72,83]

A recent review of the literature concluded that FH patients who use dietary plant stanols from 6 years onwards and a combination of statin and dietary stanol from 10 years onwards, will benefit from a 21% lower LDL-C burden compared with non-treated FH patients.[122]

Secondary prevention

Arterial disease

Once arterial disease is diagnosed, a strict medical plan is initiated to treat risk factors and to prevent future cardiovascular events. In addition to medication, following a heart-healthy diet lowers the risk of any further cardiovascular events.[123] Plant stanol ester offers an effective and recommended means[124] to lower total cholesterol and LDL-C, also in secondary prevention.[27,125]

Summary

- Plant stanol ester has been shown to be equally effective in different population and patient groups, regardless of age, sex, genetics or dietary preferences
- The relative cholesterol-lowering effect of plant stanol ester is independent of baseline cholesterol values
- Maintaining low cholesterol levels throughout life is the most effective way to prevent coronary events, so cholesterol-lowering dietary tools should be utilised as early as possible – in childhood if needed
- Plant stanol ester is an effective and safe tool for cholesterol lowering in all patient groups

Plant stanol ester complements other lifestyle changes and cholesterol medication

The main principles of a cholesterol-lowering diet are a) replacing saturated fat with unsaturated fat, b) increasing the intake of soluble fibre, and c) using foods with added plant stanol ester.[e.g.126] Adapting any of these changes to a daily diet is beneficial, but together they deliver the best results.

Plant stanol ester is effective in any kind of diet

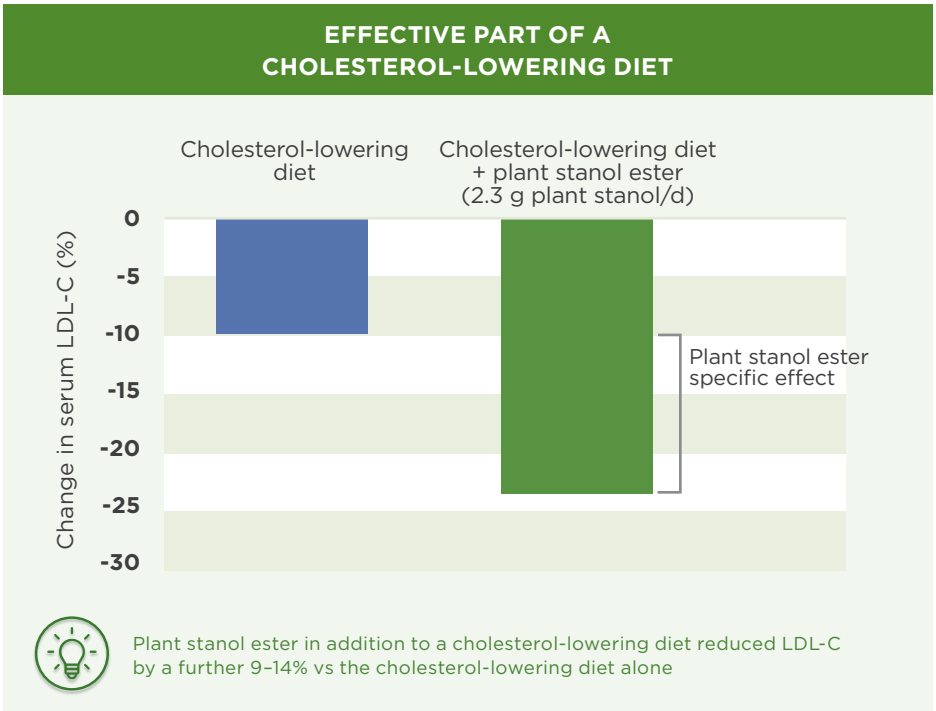
The reduction in LDL-C achieved with plant stanol ester is independent of the background diet. Plant stanol ester works just as well in a typical 'Western-type' diet with a relatively high content of saturated fat and cholesterol,[e.g.22] as in heart-healthy diets low in saturated fat and cholesterol.[72,73,86,92]

Diets already low in cholesterol do not diminish the cholesterol-lowering effect of plant stanol ester. Dietary cholesterol is only about 30% of cholesterol entering the intestine with the majority of cholesterol deriving from the bile solution secreted by the liver. Therefore, plant stanol ester works effectively also when a low-cholesterol diet is consumed,[73,79,92] reducing the absorption of mainly biliary cholesterol.[27]

The combined cholesterol-lowering effect of plant stanol ester and different types of heart-healthy diets has been examined in several studies. The studies have shown that plant stanol ester is an effective cholesterol-lowering agent as part of a diet that is already healthy and lipid-lowering. Compared to the low-fat diet alone, the low-fat diet with plant stanol ester reduced LDL-C by an additional 9–14% (Fig 10).[73] Similar results have been shown with a strictly controlled lipid-lowering diet[72,92] and in children consuming low-fat, low-cholesterol diets.[79]

Fig 10.
A cholesterol-lowering diet reduced LDL-C significantly by 10% within 8 weeks. The same diet with the addition of plant stanol ester resulted in further 14% reduction in LDL-C. Adapted from Hallikainen and Uusitupa 1999.[73]

LDL-C=low-density lipoprotein cholesterol.



With increasing research data, the perception of a heart-healthy diet has shifted from the strictly low-fat, low-cholesterol diet, to a diet that is not necessarily low in fat, but has a healthy fat composition. One example of this is the traditional Mediterranean diet. Athyros *et al.*[86] compared the effects of plant stanol ester and the Mediterranean diet on blood lipid levels, and estimated the CVD risk in mildly hypercholesterolaemic individuals. Both lipid-lowering strategies were effective in lowering the estimated risk of CVD. With plant stanol ester, the reduction in estimated risk was mainly due to a significant and steady reduction in LDL-C concentration. The Mediterranean diet gradually reduced several of the CVD risk factors, and by 4 months its effects became comparable to those seen in the plant stanol ester group (Fig 11). Although combining plant stanol ester with the Mediterranean diet has not been studied, it can be assumed that this combination would be the most beneficial dietary approach, allowing individuals to benefit from the changes induced by the total diet quality and from the more precise LDL-C reduction achieved with plant stanol ester.

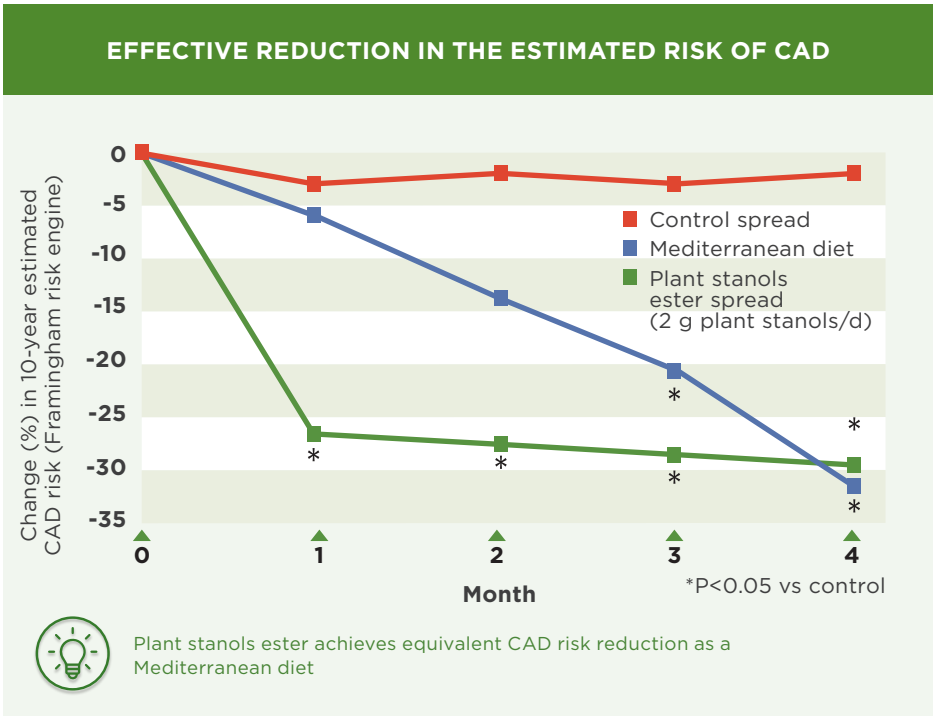


Fig 11.
A Plant stanols ester is as effective at lowering the estimated risk of CAD as a Mediterranean diet. Adapted from Athyros et al. 2011.[86]

CAD=coronary artery disease.

An additive cholesterol-lowering effect to statins

While plant stanol ester partially blocks the absorption of cholesterol in the digestive tract, the most widely used cholesterol-lowering drugs – HMG-CoA reductase inhibitors, or more commonly statins – inhibit the synthesis of cholesterol. Owing to the different mechanisms of action, the cholesterol-lowering effects of statins and plant stanol ester are additive.

Plant stanol ester can be combined with cholesterol-lowering statin medication for additional LDL-C reduction (Fig 12).[e.g. 57,65,87] In clinical studies, dietary plant stanols have been shown to induce an average incremental decrease in plasma LDL-C levels of 10% when added on top of statin therapy. This reduction is superior to that obtained by doubling the statin dose (6–7%).[24,127] Moreover, evidence suggests that 25% of statin-treated patients exhibit inadequate LDL-C lowering as a result of low endogenous cholesterol synthesis, and may benefit more from approaches that target cholesterol absorption.[128]

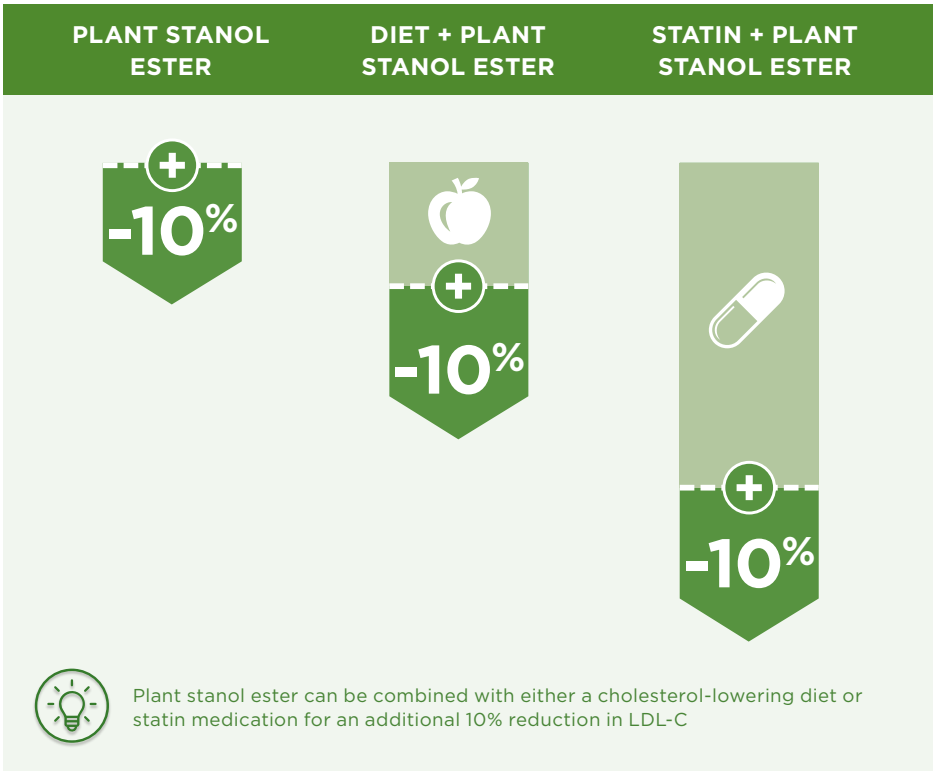


Fig 12. *Plant stanol ester (1.5–3 g of plant stanols a day) lowers cholesterol as part of any kind of lifestyle by 7–12.5% on average. Best total results are achieved when other dietary alterations are implemented as well. Combining plant stanol ester with statin medication may help to postpone the need to increase the statin dose or help reach further reduction when maximal statin dose is already in use. Adapted from Gylling et al. 2014;[24] De Jong et al. 2008;[57] Blair et al. 2000.[65]*

LDL-C=low-density lipoprotein cholesterol.

Plant stanol ester consumption has been studied in various patient groups and populations using statins: hypercholesterolaemic but otherwise healthy individuals,[57,65,66,69,93] adults and children with FH,[83,129] coronary patients,[27,70] cardiac transplant recipients,[82] and people with type 1[87] or type 2 diabetes.[28]

Adherence to statin treatment varies widely,[130] and has been reported to be poor in both the short and long term. Studies indicate that adherence to statin therapy could be improved in those consuming functional cholesterol-lowering foods.[130]

Summary

- The reduction in LDL-C achieved with plant stanol ester is independent of background diet
- Plant stanol ester is an effective cholesterol-lowering agent as part of a diet that is already healthy and lipid lowering
- The distinct mechanism of action of plant stanols for reducing cholesterol absorption in the intestine also enables an additive effect to statins
- Plant stanols can provide an additional 10% improvement in cholesterol lowering compared with statin medication alone

Prevention and treatment guidelines recommending plant stanol ester

The role of plant stanol ester as part of a cholesterol-lowering diet has been acknowledged in prevention and treatment guidelines and position papers issued by international bodies such as the International Atherosclerosis Society,[126] the European Society of Cardiology,[131,132] the European Atherosclerosis Society,[e.g.24,129] and the World Health Organization.[133]

Clinically proven efficacy and safety have ensured that plant stanol ester has become an integral part of the dietary treatment of high cholesterol in primordial and primary prevention, as well as in different patient groups (table 1, pages 38–39). The European Atherosclerosis Society consensus panel from 2014 defines the target groups for plant stanol ester as:[24]

- Individuals who have elevated serum cholesterol levels and are at low or intermediate global cardiovascular risk but who do not need cholesterol-lowering medication
- High and very high risk patients, such as patients with diabetes, who fail to achieve LDL-C targets on statins alone, or are statin intolerant
- Adults and children (from the age of 6 years) with FH

Table 1.
Key guidelines that encourage clinicians to consider plant stanol ester as part of the dietary management of hypercholesterolaemia.

Patient group	Guideline
Primordial and primary prevention	The Sixth Joint Task Force of the European Society of Cardiology and Other Societies on Cardiovascular Disease Prevention in Clinical Practice. Developed with the special contribution of the European Association for Cardiovascular Prevention & Rehabilitation (EACPR). *Atherosclerosis 2016; 252: 207–274.* The Task Force for the management of dyslipidemias of the European Society of Cardiology (ESC) and the European Atherosclerosis Society (EAS) Mach F, Baigent C, Catapano AL *et al*. ESC/EAS Guidelines for the management of dyslipidaemias: lipid modification to reduce cardiovascular risk. *Eur Heart J 2019; doi:10.1093/eurheartj/ehz455.* National Lipid Association Jacobson TA, Ito MK, Maki KC *et al.* National Lipid Association recommendations for patient-centered management of dyslipidemia: part 1 – full report. *J Clin Lipidol 2015; 9(2): 129–169.* Joint British Societies JBS 3 board: Joint British Societies' consensus recommendations for the prevention of cardiovascular disease. *Heart 2014; 100: ii1–ii67.* International Atherosclerosis Society An International Atherosclerosis Society Position Paper: Global recommendations for the management of dyslipidemia. *J Clin Lipidol 2014; 8(1): 29–60.* Joint WHO/FAO Expert Consultation Report of a Joint WHO/FAO Expert Consultation: Diet, nutrition, and the prevention of chronic diseases. *WHO Technical Report Series, No.797 – TRS 797, 2003.*
Familial hypercholesterolaemia	European Atherosclerosis Society • Wiegman A, Gidding SS, Watts GF *et al.* Familial hypercholesterolaemia in children and adolescents: gaining decades of life by optimizing detection and treatment. *Eur Heart J 2015; 36(36): 2425–2437.* • Nordestgaard BG, Chapman MJ, Humphries SE *et al.* Familial hypercholesterolaemia is underdiagnosed and undertreated in the general population: guidance for clinicians to prevent coronary heart disease. Consensus statement of the European Atherosclerosis Society. *Eur Heart J 2013; 34: 3478–3490*.

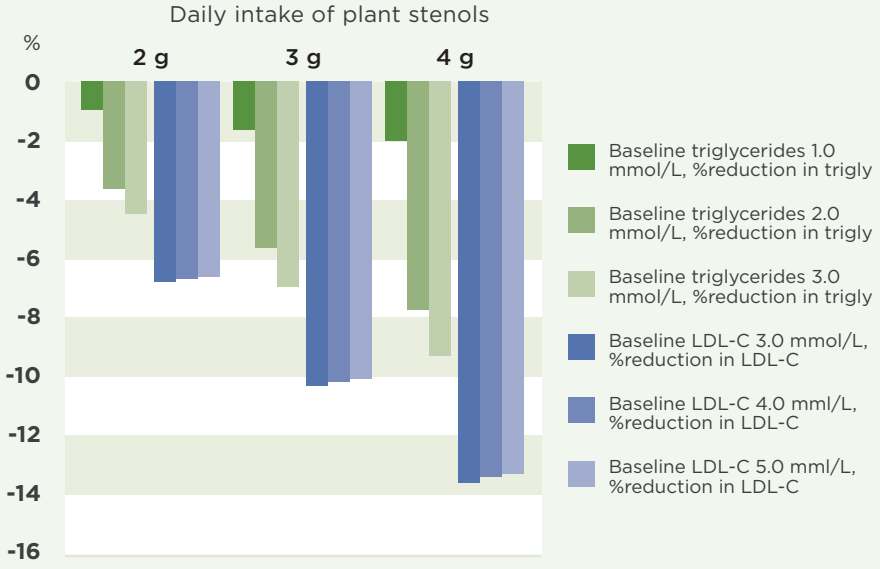
Patient group	Guideline
Diabetes	American Diabetes Association • Standards of Medical Care in Diabetes. Cardiovascular Disease and Risk Management. *Diabetes Care 2015; 38: S49–S57.* • Evert AB, Boucher JL, Cypress M *et al.* Nutrition therapy recommendations for the management of adults with diabetes. A position statement of American Diabetes Association. *Diabetes Care 2013; 36: 3821–3842.*
Children	National Heart, Lung, and Blood Institute Integrated Guidelines for Cardiovascular Health and Risk Reduction in Children and Adolescents. *Pediatrics 2011; 128: Suppl 5: S1–S44.* American Academy of Pediatrics Stephen R. Daniels, Frank R. Greer and the Committee on Nutrition. Lipid Screening and Cardiovascular Health in Childhood. *Pediatrics 2008; 122: 198–208.*
Secondary prevention	American Diabetes Association & American College of Cardiology Foundation Brunzell JD, Davidson M, Furberg CD *et al.* Lipoprotein Management in Patients With Cardiometabolic Risk: Consensus Conference Report From the American Diabetes Association and the American College of Cardiology Foundation. *J Am Coll Cardiol 2008; 51: 1512–24.*

Beyond cholesterol reduction

Effects of plant stanol ester on triglycerides

The effect of plant stanol ester on serum triglyceride concentration seems to be dependent on the baseline values. Plant stanol ester does not have a significant effect on serum triglyceride concentrations in individuals with normal levels.[e.g.22] Plant stanol ester has been shown, however, to lower the concentrations in individuals with elevated baseline serum triglyceride levels.[80,104,134] The higher the baseline value, the larger the reduction, both absolute and relative (Fig 13). Plat and Mensink[135] hypothesised that the effect of plant stanol ester on serum triglyceride concentrations originates from a lowered hepatic production of large triglyceride-rich very low density lipoprotein-1 (VLDL-1) particles, but the exact mechanism is unknown.

PREDICTED RELATIVE CHANGE IN SERUM TRIGLYCERIDES AND LDL-C



The higher the baseline serum triglyceride level, the greater the reduction in LDL-C achieved with plant stanol ester

Fig 13. *Predicted relative changes in serum triglyceride and LDL-C concentrations at different plant stanol intakes and baseline concentrations. Percentage reductions in LDL-C are dose dependent but of similar magnitude at all baseline concentrations (the blue series). However, percentage reductions in serum triglycerides are also dose dependent but significant reductions are only seen when the baseline concentration is elevated (≥2.0 mmol/L; the green series). Adapted from Naumann et al. 2008.[134]*

LDL-C=low-density lipoprotein cholesterol.

Effects of plant stanol ester on arterial health and endothelial function

At population level, even modest reductions in LDL-C level have been shown to significantly decrease the incidence of CHD, and lower LDL-C levels sustained for decades result in lower CHD risk also at individual level.[122,136,137] Despite the well established LDL-C-lowering benefit, however, the endpoint benefit of plant stanol ester on coronary health has not been confirmed in a clinical intervention study.

Endothelial dysfunction is an early indicator of atherosclerotic changes in the vascular wall, preceding the formation of atherosclerotic plaque. This surrogate marker for atherosclerosis development has been used to evaluate the possible health benefit of lowering cholesterol with plant stanol ester. Most intervention studies with plant stanol ester where blood vessel functions have been measured have been conducted in individuals without impaired blood vessel function.[56,67,77,88,89,93,102] Unfortunately, to date, no clinical studies have been conducted using impaired endothelial function as inclusion criteria. Raitakari *et al.*[77] suggested that in individuals with impaired baseline endothelial function, the consumption of plant stanol ester might be associated with beneficial changes in arterial elasticity and endothelial function. There is also indication from a 6-month intervention study that plant stanol ester may counteract the impairment of arterial stiffness in men.[67] Furthermore, in a case-control study by Raitakari *et al.*[76] the arterial elasticity of long-time regular plant stanol ester margarine users was better compared with non-users.

Most of the above mentioned studies were of short dutation (4–16 weeks), the longest intervention lasting for 1 year.[56] As atherosclerosis development is a life-long process, it is likely that a modest LDL-C reduction comparable to that achieved with plant stanol ester consumption will not produce measurable changes in the vascular wall in such a short time. Endothelial function may not be ideal for showing benefit from dietary interventions, as a recent study with improvement in dietary fat quality also failed to show any change in endothelial function despite significant LDL-C reduction.[138] To show clinical benefits from cholesterol lowering with plant stanol ester, other methods may need to be considered.

Accumulation of LCL-C in the arterial wall is known to cause ASCVD. While high plasma concentrations of LDL drive this, LDL quality may also contribute. Ruuth *et al.*[139] examined whether differences in LDL quality were linked with LDL composition and CAD death, identifying the susceptibility of LDL to aggregate as a novel measurable and modifiable factor in the progression of ASCVD. Excess consumption of saturated fats increases LDL-C aggregation susceptibility, while consumption of plant stanol ester enriched spread decreases it. Thus, these dietary changes appear to influence, in addition to LDL-C levels, also LDL-C quality and potentially the future risk of ASCVD.[139]

Possible new indications

Current plant stanol ester research looks beyond the cholesterol-lowering effect of this ingredient – the interest is now in possible effects on immunity and inflammation. Initial results from *in vitro* studies indicate that plant stanols may have beneficial immunomodulatory effects in the cells of asthma patients.[140,141] Promising results have also emerged showing that plant stanol ester inhibited hepatic inflammation in mice, suggesting that plant stanol ester could also have a protective effect on non-alcoholic liver inflammation in humans.[142]

In 2016, Brüll *et al.* published the findings of a randomised, double-blind, placebo-controlled intervention investigating the effect of plant stanol esters on immune response in asthma patients. Asthma patients in the plant stanol ester group showed higher antibody levels after vaccination and a substantial reduction in plasma total immunoglobulin E, interleukin-1b, and tumour necrosis factor compared with the control group.[143]

Ongoing research is being undertaken at the Maastricht University Medical Center with a long-term study (follow-up 1 year) involving patients with proven mild asthma who will consume 3 g/d of plant stanols. In addition to evaluating changes in asthma symptoms, changes in lipoprotein metabolism and cardiovascular risk will be explored.[144]

Summary

- Emerging research has explored the benefits of plant stanols further than just LDL-C lowering
- Plant stanol ester has been shown to lower triglyceride concentrations in individuals with elevated baseline serum triglyceride levels
- In individuals with impaired baseline endothelial function, the consumption of plant stanol ester might be associated with beneficial changes in arterial elasticity and endothelial function
- There are possible effects of plant stanols on immunity and inflammation, for example in the immunomodulatory activity in the cells of asthma patients or hepatic inflammation with respect to non-alcoholic liver inflammation

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