Clinical update

Fish oil and omega-3 fatty acids in cardiovascular disease: do they really work?

Daan Kromhout1*, Satoshi Yasuda2, Johanna M. Geleijnse1, and Hiroaki Shimokawa2*

1Division of Human Nutrition, Wageningen University, PO Box 8129, 6700 EV Wageningen, The Netherlands; and 2Department of Cardiovascular Medicine, Tohoku University Graduate School of Medicine, Seiryo-machi, Aoba-ku, Sendai 980-8574, Japan

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Omega-3 fatty acids, which are found abundantly in fish oil, exert pleiotropic cardiometabolic effects with a diverse range of actions. The results of previous studies raised a lot of interest in the role of fish oil and omega-3 fatty acids in primary and secondary prevention of cardiovascular diseases. The present review will focus on the current clinical uses of omega-3 fatty acids and provide an update on their effects. Since recently published trials in patients with coronary artery diseases or post-myocardial infarction did not show an effect of omega-3 fatty acids on major cardiovascular endpoints, this review will examine the limitations of those data and suggest recommendations for the use of omega-3 fatty acids.

Keywords
Fish oils • Cardiovascular disease

Introduction

In 1929, the essential fatty acids were discovered by the biochemists Evans and Burr.1 They showed that mammals do not possess enzymes able to synthesize double bonds at the n-3 and n-6 positions of the carbon chain of a fatty acid. Therefore, humans must obtain the essential fatty acids linoleic acid (C18:2 n-6) and alpha linolenic acid (ALA, C18:3 n-3) from dietary sources. Alpha linolenic acid can be extended to eicosapentaenoic acid (EPA C20:5 n-3) and docosahexaenoic acid (DHA C22:6 n-3) through elongation and desaturation. Fish oil is a rich source of these omega-3 fatty acids.

In 1937, the British physiologist Hugh Sinclair visited Evans and became interested in the possibility that deficiencies in polyunsaturated fatty acids could cause coronary artery diseases (CAD). In 1944, he undertook his first visit to the Inuit and became convinced that their diet protects against atherosclerosis and Western diseases.2 In a letter to the Lancet, he hypothesized in 1956 that omega-3 fatty acids may be responsible for the protective effect of their diet.3 This view was contrary to the dogma of that time that all animal fats are harmful. In the 1970s, he joined the Danish investigators Bang and Dyerberg4,5 during one of their expeditions to Greenland. They found that the Inuit consumed ~400 g of seafood per day and their average intake of omega-3 fatty acids was 14 g per day compared with 3 g per day among Danes. An epidemiological study showed that the incidence of myocardial infarction (MI) was 10 times lower among the Inuit compared with the Danes.6 The difference between the Inuit and the Danes in the intake of omega-3 fatty acids was reflected in their fatty acid composition of platelets. Differences were also observed in haemostatic factors, bleeding time, serum triglycerides, and high-density lipoprotein (HDL)—cholesterol levels. To show that these associations are causal, Sinclair put himself in 1977 on an Inuit diet for 100 days.7 His bleeding time rose from 3–5 to 50 min and substantial decreases were observed in blood platelets, erythrocytes, packed cell volume, and haemoglobin. The triglyceride-rich very low-density lipoprotein (VLDL) fell and the HDL fraction increased considerably. A substantial increase in the EPA concentration and a marked decrease in the linoleic acid concentration of cholesteryl esters were noted. Sinclair concluded from this experiment that it is necessary to have the right balance of omega-3 and omega-6 fatty acids to prevent thrombotic disorders.

In 1985, Kromhout et al.8 showed in the Zutphen Study, a prospective cohort study in the Netherlands, that eating fish once or twice per week was associated with a lower risk of fatal CAD
compared with men who did not eat fish. Four years later in 1989, Burr et al. showed in the Diet and Reinfarction Trial (DART) that cardiac patients who received an advice to add two fatty fish meals per week to their diet reduced CAD mortality significantly, compared with those who did not get a fish advice. The results of these studies raised a lot of interest in the role of fish oil and omega-3 fatty acids in primary and secondary prevention of cardiovascular diseases (CVD). In this article, we summarize the mechanisms of the action of omega-3 fatty acids and the results of cohort studies and clinical trials on omega-3 fatty acids and CVD. Finally, we draw conclusions on whether omega-3 fatty acids reduce the incidence of these diseases.

Mechanisms of action of omega-3 fatty acids

The cardiometabolic effects of omega-3 fatty acids continue to be extensively investigated and remain an active area of research. Omega-3 fatty acids can ultimately increase arrhythmic thresholds, reduce blood pressure, improve arterial and endothelial function, reduce platelet aggregation, and favourably affect autonomic tone (Figure 1). In this section, we briefly review recent studies that extend our knowledge on the cardioprotective effects of omega-3 fatty acids.

Anti-inflammatory effects

Recently, the anti-inflammatory effects of omega-3 fatty acids have attracted much attention. Omega-3 fatty acids reduce the content of arachidonic acid (AA) in membrane phospholipids in platelets, endothelial cells, and inflammatory cells with a resultant reduced production of AA-derived pro-inflammatory mediators, including prostaglandin (PG)-E₂, thromboxane (TX)-B₂, leukotriene (LT)-B₄, hydroxyicosatetraenoic acid (5-HETE), and LT-E₄. Importantly, EPA also acts as a substrate for cyclo-oxygenase and lipoxigenase enzymes, which could increase a different family of eicosanoids—the three-series PGs and TXs. In addition to these anti-inflammatory effects, omega-3 fatty acids have a number of other effects that may occur either downstream of altered eicosanoid production or independent of this activity. For example, the effects of omega-3 fatty acids on inflammatory cytokine expression could be at least in part through modulating intra-cellular signalling pathways that inactivates transcriptional factors. Recent studies demonstrated that omega-3 fatty acids could down-regulate the activity of the nuclear factor (NF)-κB, which plays a key role in the regulation of gene expression in inflammatory responses and has been implicated in the pathogenesis of CVD. The inhibition of NF-κB activation can be mediated by the mechanism that is related to the activation of peroxisome proliferator-activated receptor (PPAR) or the inhibition of toll-like receptors.

Rho-kinase is a downstream effector of the small GTPase Rho and mediates diverse cellular functions, such as smooth muscle cell contraction, cell migration, and proliferation. Rho-kinase also up-regulates pro-inflammatory molecules and down-regulates endothelial nitric oxide (NO) synthase (eNOS). It has been recently demonstrated that long-term treatment with EPA significantly inhibits Rho-kinase activation in the myocardium subjected to ischaemia–reperfusion in vivo (Figure 2).

In addition, supplementation with EPA and DHA could exert a protective effect on the heart through improvement in mitochondrial function and the efficiency of ATP generation. This effect may be due to changes in mitochondrial membrane phospholipids composition and improved efficiency of ATP generation.
Inhibition of platelet aggregation

Omega-3 fatty acids decrease the risk of thrombosis by inhibiting platelet aggregation. Importantly, omega-3 fatty acids inhibit platelet TXA2 synthesis and acts as antagonists of the pro-aggregatory TXA2/PG H2 receptor in human platelets in vitro.19 Supplementing a diet with omega-3 fatty acids down-regulate mRNA expression of platelet-derived growth factor-A and -B in mononuclear blood cells in humans.20

Triglyceride-lowering effects

Omega-3 fatty acids play an important role to regulate genes that are critical for controlling lipid homeostasis. Omega-3 fatty acids decrease VLDL assembly and secretion, resulting in diminished triacylglycerol production, through a decreased activity of sterol receptor element-binding protein-1c, which is the key switch in controlling lipogenesis.21 In addition, omega-3 fatty acids could promote β-oxidation simultaneously in mitochondria and/or peroxisomes, possibly through the activation of peroxisome PPAR-α, leading to the reduction of fatty acids substrate for triglyceride synthesis.21,22 The remnant lipoprotein (RLP), produced from the triacylglycerol-rich chylomicrons and VLDL, exerts potent pro-atherogenic effects and is thus regarded as an important risk factor of CVD.22,23 The involvement of RLP has been suggested in the pathogenesis of sudden cardiac death22 and restenosis after coronary angioplasty.23 Although omega-3 fatty acids do not have a major effect on fasting total cholesterol and LDL cholesterol levels, EPA effectively reduces RLP in hyperlipidaemic patients.24

Improvement of endothelial function

Long-term treatment with fish oils augments endothelium-dependent relaxation of normal porcine coronary arteries,25 for which EPA, a major omega-3 fatty acids of fish oils, is responsible for the augmentation.26 This augmenting effect of EPA was also noted in porcine coronary microvessels.27 Long-term treatment with fish oils improves endothelium-dependent relaxation of hypercholesterolaemic and atherosclerotic porcine coronary arteries28 and femoral veins.29 Eicosapentaenoic acid augments endothelium-dependent relaxation by NO as well as that by endothelium-derived hyperpolarizing factor.30 Docosahexaenoic acid alters caveolae microenvironment not only by modifying membrane lipid composition, but also by changing distribution of major structural proteins, eventually increasing eNOS activity in human umbilical vein endothelial cells.31 Nitric oxide also inhibits platelet aggregation and adhesion, leucocytes adhesion, and smooth muscle cell proliferation. In addition, in endothelial cells,
co-incubation with DHA following challenge with interleukin (IL)-1, IL-4, tumour necrosis-α, or lipopolysaccharide decreases expression of vascular cell adhesion molecule-1, intercellular adhesion molecule-1 and E-selectin, and secretion of IL-6 and IL-8.

**Plaque stabilization**

As mentioned above, through their anti-inflammatory effects, omega-3 fatty acids could not only prevent the plaque development but also contribute to the plaque stabilization. The randomised clinical trial demonstrated that omega-3 fatty acids supplementation substantially increases tissue levels of EPA and DHA and decreases macrophage infiltration and thickened fibrous cap in human carotid arteries. Exacerbated release of matrix metalloproteinase (MMP) by the activated endothelium and macrophages plays a pathological role in plaque progression and instability. Eicosapentaenoic acid (EPA) and docosahexaenoic acid (DHA) inhibit production of MMPs by macrophages in a PPARα-dependent manner.

**Anti-arrhythmic effects**

The omega-3 fatty acids are incorporated into cell membranes and affect the ion-channel function of myocytes. There are several mechanisms by which omega-3 fatty acids could exert anti-arrhythmic effects. Omega-3 fatty acids inhibit voltage-gated Na channels, prolonging relative refractory period and increased voltage that are required for membrane depolarization.

Omega-3 fatty acids also exhibit a modulatory action on L-type calcium Ca channels, resulting in lowered cytosolic free Ca and Ca influx rate and in preventing cytosolic Ca overload during ischaemic insult. Long-term treatment with EPA reduces ischaemia-induced ventricular fibrillation in pigs in vivo, for which attenuation of shortening of monophasic action potential duration through suppression of cardiac KATP channels may be involved. Anti-arrhythmic effect of omega-3 fatty acids may be mediated in part by their effects on autonomic control, especially by an increased vagal tone.

Through these mechanisms, omega-3 fatty acids may prevent ventricular tachyarrhythmias and hence decrease sudden cardiac death.

**Fish, omega-3 fatty acids, and coronary artery disease in cohort studies**

Based on the ecological studies among the Inuit, Japanese fishermen and farmers, and the Zutphen men that two different mechanisms could be responsible for the association between fish consumption and CAD. He hypothesized an acute effect on fatal CAD in cultures with a low level of fish consumption and a chronic effect in cultures with a high level of fish consumption (Figure 3).

Since 1985, results of many prospective cohort studies on fish consumption and CAD have been published, with several studies showing a protective effect although others did not. The first quantitative review was published in 1999 by Marckmann and Gronbaek and included 11 studies with 116 764 individuals. Four studies were judged to be of high quality, of which the two were performed in populations at high risk and the two in populations at low risk. In the high-risk populations, a protective association was found but not in the low-risk populations. The authors drew the conclusion that only in high-risk populations, a fish consumption of 40–60 g per day is associated with a markedly lower CAD mortality.

In 2004, two meta-analyses were published on fish consumption and fatal CAD. The study of Whelton et al. included both prospective cohort studies and case–control studies and the study by He et al. only cohort studies. Case–control studies are more prone to selection and information bias and it is particularly difficult to obtain accurate data on fish consumption in patients before the occurrence of a CAD event. Therefore, only the results of the cohort studies are summarized here. The meta-analyses by Whelton et al. and He et al. were based on 14 and 13 cohort studies, respectively. Both had approximately 220 000 participants who were followed for ~12 years.

Whelton et al. found a 17% lower incidence of fatal CAD (RR = 0.83, 95% CI 0.75–0.92) among those who consumed fish less than twice a week compared with those who ate little or no fish. A similar result was found by He et al. for fish consumed once a week (RR = 0.85, 95% CI 0.76–0.96). He et al. observed a dose–response relationship between fish consumption and CAD death and individuals who consumed fish five or more times per week had a 38% lower risk of fatal CAD (RR = 0.62, 95% CI 0.46–0.82). These associations were confirmed in
cohort studies in which, besides fish consumption, information about the intake of the omega-3 fatty acids EPA and DHA was also obtained.46–49

There is less evidence for a relationship between fish consumption and non-fatal MI. Based on the results of their meta-analysis, He et al.45 concluded that the evidence for an inverse association between fish consumption and non-fatal MI was weak, even though there was a significant association for those eating fish five times per week or more. This conclusion was confirmed by De Goede et al.,49 who found that consuming fish less than once per month up to once per week was not associated with non-fatal MI in a population-based study in the Netherlands. However, a Japanese cohort study showed that a high level of fish consumption may be protective against non-fatal CAD. In the Japan Public Health Center-Based Study, the relative risk (RR) of non-fatal MI was 0.43 (95% CI 0.23–0.81) in participants with a median fish consumption of 180 g per day compared with participants with a daily consumption of 23 g per day.48 These results support the outcome of the meta-analysis of He et al.45 that only a high level of fish consumption may reduce the risk of non-fatal MI.

Fish, omega-3 fatty acids, and sudden death in observational studies

The hypothesis that fish consumption may be protective against sudden cardiac death is derived from the DART trial. This secondary prevention trial showed a significant 33% reduction in CAD mortality in cardiac patients who consumed at least two portions of fatty fish per week and were followed for 2 years. The authors suggested that the protective effect of fatty fish may be due to preventing ventricular fibrillation during acute ischaemia. This hypothesis was tested in two population-based case–control studies.50,51

Siscovick et al.50 identified 334 patients with primary cardiac arrest and 493 population-based controls. An average intake of 185 mg per day of EPA–DHA corresponding to eating fatty fish once a week was associated with a 50% lower risk of primary cardiac arrest (OR = 0.5, 95% CI 0.4–0.8). An even stronger association was observed for the corresponding quartile of red blood cell membrane omega-3 fatty acids (OR = 0.3, 95% CI 0.2–0.6). Similarly, a strong inverse relation was found between baseline blood levels of long-chain omega-3 fatty acids and sudden death in the Physicians’ Health Study.51 The RR value was 90% lower in those in the highest compared with the lowest quartile of omega-3 fatty acids (RR = 0.10, 95% CI 0.02–0.48).

The evidence from prospective cohort studies on fish, omega-3 fatty acids, and sudden cardiac death is less convincing than that from population-based case–control studies.52–54 Albert et al.53 showed, using again data from the Physicians’ Health Study, that men who consumed one fish meal per week had a 52% lower risk of sudden cardiac death (RR = 0.48, 95% CI 0.24–0.96) compared with those who consumed fish less than once a month. A significant inverse dose–response relationship with sudden cardiac death was not observed for the intake of omega-3 fatty acids, although the data suggested that an intake of ~200 mg omega-3 fatty acids per day compared with ~10 mg per day was associated with a lower risk of sudden cardiac death.

In contrast to these findings, sudden cardiac death was not significantly inversely associated with fish consumption in the Western Electric Study.55 In this study, information on causes of death was obtained only from death certificates. Sudden cardiac death was defined as death occurring no more than 12 h after the onset of the terminal acute illness. In the Physicians’ Health Study, detailed information was available from next of kin, medical records, and autopsy reports; and sudden death was defined as death within 1 h of the onset of symptoms. This definition of sudden cardiac death is superior to the one used in the Western Electric Study.

The association between long-term fish consumption, omega-3 fatty acids, and sudden cardiac death was also investigated in the Zutphen Study.54 Long-term fatty fish consumption was inversely associated with sudden coronary death, and men who consumed fatty fish had a 54% lower risk (RR = 0.46, 95% CI 0.27–0.78) than those who did not eat fatty fish. Lean fish consumption was not associated with sudden coronary death. The intake of omega-3 fatty acids was also inversely related to sudden coronary death but this association was not statistically significant.

In summary, the results of the population-based case–control and prospective cohort studies suggest a protective effect of fish consumption on cardiac arrest and sudden death. The two case–control studies showed the strongest effect for the omega-3 fatty acids measured in blood.

Fish oils and cardiovascular diseases in randomized trials

Several trials tested the hypothesis that omega-3 fatty acids reduce fatal CAD and sudden death. The first meta-analysis of these trials was published in 2002,55 followed by others.56–59 However, several meta-analyses included not only trials in which the effect of omega-3 fatty acids in fish oils was investigated but also trials in which a fish advice or margarines enriched with ALA were given.55,56,58 One meta-analysis on fish oils included besides patients with MI, CAD, and heart failure also patients with peripheral vascular diseases, hypercholesterolaemia, and implanted cardioverter defibrillators (ICDs).56 Only the meta-analysis by León et al.57 evaluated the effect of EPA–DHA in a homogeneous group of patients with CAD or had had an MI. They used fatal CAD, sudden cardiac death, and severe arrhythmias as endpoints.

In three trials, patients with an ICD were included. In these trials, fish oil capsules containing an additional amount of 0.9–2.8 g omega-3 fatty acids per day reduced the risk of severe arrhythmias by 10% (OR = 0.90, 95% CI 0.55–1.46).57 A similar result was found in a meta-analysis by Brouwer et al.60 based on the same studies. Eight trials using fish oil capsules containing 0.9–2.8 g of EPA–DHA showed a significant 20% reduction of cardiac death (OR = 0.80, 95% CI 0.69–0.93).57 In four trials, an additional amount of 0.9–2.4 g of EPA–DHA per day reduced the incidence of sudden cardiac death by 26% (OR = 0.74, 95% CI 0.59–0.92).57 The results for fatal CAD and sudden death were dominated by
those of the GISSI-Prevenzione trial that contributed >85% to both endpoints. In 2010, the results of the Alpha Omega, OMEGA, and SU.FOL.OM3 trials were published. The results of these trials and those of the large trials published before 2010—the GISSI-Prevenzione trial, the secondary prevention component of the JELIS trial, and the GISSI Heart Failure trial—will be discussed in detail (Table 1). The GISSI-HF published in 2008 and the three trials published in 2010 were not included in the meta-analysis of Leon et al.

The number of patients included in these trials ranged from 2501 to 11 324 with 15–26% females. Three trials included post-MI patients, two trials CAD patients, and one trial heart failure patients. The average age of the patients varied between 59 and 69 years. Two trials recruited patients in the 1990s and used an open-label design. The remaining trials were initiated between 2002 and 2007 and were double-blind. The OMEGA trial had a 12-month follow-up and in the other trials the average follow-up period varied between 41 and 56 months. In four trials, the patients received fish oil capsules containing 600–900 mg of EPA–DHA per day and in the JELIS trial 1800 mg of EPA per day. In the Alpha Omega Trial, margarine spread provided an average additional intake of EPA–DHA of ≏400 mg per day.

The most important commonly used endpoints in these trials were major cardiovascular events, fatal CVD, fatal CAD, and sudden death. The strongest effects were observed in the GISSI-P trial for patients surviving a recent MI. In this trial, an additional amount of EPA–DHA of 900 mg per day reduced significantly fatal CVD by 30%, fatal CAD by 35%, and sudden death by 45%. In the GISSI-HF trial, in which heart failure patients were included, fatal CVD was significantly reduced by 10%, sudden death non-significantly by 7%, and first hospital admissions for ventricular arrhythmias significantly by 28%. The JELIS trial showed that an additional intake of 1800 mg of EPA per day reduced only major coronary events (fatal and non-fatal CAD, unstable angina, percutaneous coronary intervention, and coronary artery bypass grafting). The three trials published in 2010 included either post-MI or CAD patients. Additional amounts of EPA–DHA varying from 400–800 mg/day did not reduce cardiovascular events.

### Table 1  Effects of fish oil on cardiovascular diseases in trials with patients with heart disease

<table>
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<tr>
<th></th>
<th>GISSI-P 1999 (41)</th>
<th>JELIS 2007 (64)</th>
<th>GISSI-HF 2008 (65)</th>
<th>Alpha Omega 2010 (61)</th>
<th>OMEGA 2010 (62)</th>
<th>SU.FOL.OM3 2010 (63)</th>
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<td>47</td>
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MI, myocardial infarction; CAD, coronary artery diseases; HF, heart failure; MCE, major cardiovascular event; CVD, cardiovascular diseases.

*Fatal and non-fatal events.
P, 0.05.
The strongest reductions in cardiovascular endpoints were obtained in the oldest trials. An explanation could be differences in study design. The GISSI-P and the JELIS trial used an open label design. This may have confounded the results of these trials, because placebo capsules were lacking. Another explanation could be that the patients in the more recent trials were very well treated not only by antithrombotics but also by antihypertensives and statins. Compared with the recent trials, the treatment level with statins was low in the GISSI-P trial (29%). This could be the reason for the high risk of fatal CAD and sudden death in the GISSI-P trial compared with the Alpha Omega Trial. The absolute risk for fatal CAD in the control group was 15.8/1000 person-years in the GISSI-P and 8.9/1000 person-years in the Alpha Omega Trial. For sudden death, the rates were 10.4/1000 person-years in the GISSI-P and 3.7/1000 person-years in the Alpha Omega Trial. A likely explanation is that these differences in absolute risk between the trials were responsible for the absence of an effect of EPA–DHA on fatal CAD and sudden death in the recent trials.

Those differences in absolute risk of fatal CAD and sudden death could play an important role in explaining the different results in the GISSI-P and the Alpha Omega Trial. This is supported by the results of the subgroup analysis of patients in the Alpha Omega Trial who also had diabetes. The absolute risk of fatal CAD in the control group of diabetes patients in the Alpha Omega Trial was 17.1/1000 person-years. This is in the same order of magnitude as the absolute risk in the control group of the GISSI-P trial. In the diabetes patients who received an additional amount of 400 mg of EPA–DHA per day, a significant reduction in fatal CAD was obtained comparable with the GISSI-P trial (Figure 4). Similar results were found in the Alpha Omega Trial for sudden death and ventricular arrhythmia-related events, although these effects were not statistically significant.

**Emerging issues on the effects of fish oils/omega-3 fatty acids**

Results of observational prospective cohort studies and randomized trials in subjects with or without CVD published before 2000 demonstrated that diets with higher amounts of omega-3 fatty acids or supplements with omega-3 fatty acids reduced cardiovascular mortality. These results formed the basis for recommendations, including the American Heart Association Guidelines, that patients with documented CAD should be advised to take 900–1000 mg of omega-3 fatty acids (EPA–DHA combined) per day. However, this recommendation was challenged in a review and meta-analysis published by Hooper et al in 2006. They concluded that there was no clear benefit of additional amount of omega-3 fatty acids on cardiovascular events. In addition, the three recently published double-blind trials—the Alpha Omega, the OMEGA, and the SU.FOL.OM3—did not show an effect of an additional amount of EPA–DHA on major cardiovascular endpoints. These negative results with omega-3 fatty acids supplementation were disappointing but were obtained in the current practice where other optimal conventional drug therapy was performed. It should be pointed out, however, that the OMEGA and the SU.FOL.OM3 trial were also underpowered.

In addition, there is some evidence for possible pro-arrhythmic effects of omega-3 fatty acids in certain subgroups with CVD. In the three randomized controlled trials of patients with an
implantable cardioverter defibrillator (ICD) and a history of ventricu-
lar tachyarrhythmias, fish oil of omega-3 fatty acids did not show a
significant benefit on the risk of appropriate ICD shocks. In a trial of
patients with stable angina pectoris without previous MI, a
detrimental effect of omega-3 fatty acids on sudden death was ob-
erved.67 Thus, further studies are needed to determine which
patient population may or may not benefit from omega-3 fatty
acids supplementation. Evidence is also insufficient regarding the
optimal dose, source (oily fish or fish-oil supplements), and formu-
lation of EPA and/or DHA in order to reduce cardiovascular
events.68

Recently, a potential new indication of omega-3 fatty acids has
been demonstrated, that is heart failure.69 In the GISSI-HF trial,65
a placebo-controlled trial of approximately 7000 patients with
class II to IV heart failure, the patients were randomized to 1 g
of omega-3 fatty acids (containing 850–882 mg of EPA plus
DHA), rosuvastatin (10 mg), both of them, or dual placebo. This
study was performed in addition to well-established current ther-
apies, and the results showed a significant benefit of omega-3 fatty
acids.66 However, the optimal dose of omega-3 fatty acids remains
to be determined depending on different stages and/or aetiology of
heart failure and underlying mechanisms.67 Growing evidence
demonstrates anti-inflammatory effects of omega-3 fatty acids,
including reduced circulating levels of inflammatory cytokines and
AA-derived eicosanoids, and elevated plasma adiponectin.18 In
animal studies, fish oil favourably alters cardiac mitochondrial func-
tion.19 All of these effects may work together to prevent the devel-
opment and progression of heart failure.

Several issues remain to be elucidated. First, no evidence has
been found for the optimal dosage, ratios of DHA to EPA, and
ratios of omega-3 to omega-6. Second, whether dietary intake or
therapeutic supplements are the best source of omega-3 fatty
acids is yet to be determined. These issues remain to be clari-
fied in future studies.

Conclusions
Omega-3 fatty acids exert pleiotropic, cardiometabolic effects with
a diverse range of actions, most of which are beneficial for the car-
diovascular system. Supplementation up to 1 g of omega-3 fatty
acids per day is well tolerated except dysgeusia and does not
increase the risk of bleeding. Recently published trials in patients
with CAD or after MI did not show an effect of omega-3 fatty
acids on major cardiovascular endpoints, probably due to state of
the art drug treatment. However, as suggested by the current
guidelines, the potential value of omega-3 fatty acids supplemen-
tation in patients with CAD or after MI and possibly in those
with heart failure remains to be encouraged.

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References
3. Kromann N, Green A. Epidemiological studies in the Upernavik district, Green-
208:401–406.
4. Bang HO, Dyerberg J. Plasma lipids and lipoproteins in Greenlandic west coast
5. Bang HO, Dyerberg J, Sinclair HM. The composition of the Eskimo food in north
7. Sinclair HM. Advantages and disadvantages of an Eskimo diet. In: Fumagalli R,
Kritchevsky D, Peolleti R, eds. Drugs Affecting Lipid Metabolism. Amsterdam: Else-
8. Kromhout D, Bosschieter EB, de Lezenne Coullander C. The inverse relation
between fish consumption and 20-year mortality from coronary heart disease.
9. Burr ML, Fehily AM, Gilbert JF, Rogers S, Holliday RM, Sweetnam PM, Elwood PC,
Deadman NM. Effects of changes in fat, fish, and fibre intakes on death and myo-
10. Shimokawa H. Beneficial effects of eicosapentaenoic acid on endothelial vasodila-
tor functions in animals and humans. In: Hamazaki T, Okuyama H, eds. Fatty Acids
11. Calder PC. N-3 polyunsaturated fatty acids and inflammation: from molecular
12. Adkins Y, Kelley DS. Mechanisms underlying the cardioprotective effects of
13. de Winther MP, Kantes E, Kragal G, Holker MH. NF-κB signaling in atherogen-
14. Shimokawa H, Takeshita A. Rho-kinase is an important therapeutic target in car-
16. Yada T, Shimokawa H, Hiramatsu Q, Kataja T, Shigeta F, Tanaka E, Shinozaki Y,
Morii H, Kiyooka T, Katsura M, Ohkuma S, Goto M, Ogawa Y, Kataf F. Beneficial
effect of hydroxysaffusil, a specific Rho-kinase inhibitor, on ischemia/ reperfusion
Shimokawa H. Long-term treatment with eicosapentaenoic acid ameliorates myo-
cardial ischemia-reperfusion injury in pigs in vivo. Involvement of Rho-kinase
18. Duda MK, O’Shea KM, Stanley WC. Omega-3 polyunsaturated fatty acid supple-
mentation for the treatment of heart failure: mechanisms and clinical potential.
19. Swann PG, Venton DL, Le Breton GC. Eicosapentaenoic acid and docosahexae-
oxic acid are antagonists at the thromboxane A2/prostaglandin H2 receptor in
lower levels of platelet-derived growth factor mRNA in human mononuclear
21. Nimpah H, Nambu J. Polyunsaturated fatty acid regulation of genes of lipid
22. Oi K, Shimokawa H, Hiroki J, Uwatoki T, Abe K, Matsumoto Y, Nakajima Y,
Nakajima K, Takeichi S, Takeshita A. Remnant lipoproteins from patients with
sudden cardiac death enhance coronary vasospastic activity through upregulation
23. Oi K, Shimokawa H, Hirakawa Y, Tashiro H, Nakaide R, Kozai T, Ohzeono K,
Yamamoto K, Koyanagi S, Takeshita A. Remnant lipoproteins of patients from
with sudden cardiac death enhance coronary vasospastic activity through upregulation
24. Oi K, Shimokawa H, Hirakawa Y, Tashiro H, Nakaide R, Kozai T, Ohzeono K,
Yamamoto K, Koyanagi S, Takeshita A. Postpran-
dial increase in plasma concentrations of remnant-like particles: an independent
risk factor for restenosis after percutaneous coronary intervention. J Cardiovasc
Satoh A, Temaru R, Ishikura T, Takata M, Kishida M, Kobayashi M. Joint effects of
HPiG-CoA reductase inhibitors and eicosapentaenoic acids on serum lipid profile
and plasma fatty acid concentrations in patients with hyperlipidemia. Int J Clin Lab
27. Shimokawa H, Aarhus LL, Vanhoutte PM. Dietary ω-3 polyunsaturated fatty acids augment endothelium-dependent relaxation to bradykinin in coronary microves-
28. Shimokawa H, Vanhoutte PM. Dietary cod-liver oil improves endothelium-
dependent responses in hypercholesterolemic and atherosclerotic porcine cor-
29. Komon K, Shimokawa H, Vanhoutte PM. Endothelium-dependent relaxation to aggregating platelets in porcine femoral veins and its modulation by diets. Circu-
32. De Caterina R, Cybulsky M, Clinton SK, Gimbrone MA Jr, Libby P. The omega-3 fatty acid docosahexaenoate reduces cytokine-induced expression of proather-
34. Thies F, Garry JM, Yaqoob P, Rerkasem K, Williams J, Shearman CP, Gallagher PJ, Calder PC, Grimbble RF. Association of n-3 polyunsaturated fatty acids with stab-
35. Morishige K, Shimokawa H, Matsumoto Y, Eto Y, Uwatoku T, Abe K, Sueshi K, Takeshita A. Overexpression of matrix metalloproteinase-9 promotes intravas-
41. Streppel MT, Ocké MC, Boshuizen HC, Kok FJ, Kromhout D. Long-term fish con-
45. Brouwer IA, Ratt M, Dullemeijer C, Kraemer DF, Zock PL, Morris C, Katan MB, Connor WE, Cann AM, Schouten EG, Maunuty J. Effect of fish oil on ventricular tachyarrhythmia in three studies in patients with implantable cardioverter defibril-