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Omega 3 fatty acids and cardiovascular disease—fishing for a natural treatment

Jehangir N Din, David E Newby, Andrew D Flapan

Omega 3 fatty acids from fish and fish oils can protect against coronary heart disease. This article reviews the evidence regarding fish oils and coronary disease and outlines the mechanisms through which fish oils might confer cardiac benefits.

Several areas of uncertainty remain. The optimal intake of omega 3 fatty acids is not firmly established, nor is their mechanism of action fully understood. Some studies have produced conflicting results, and concerns have been increasing about environmental contamination of certain fish. This article reviews the current evidence regarding fish oils and cardiovascular disease, their possible mechanism of action, and potential future developments and research strategies.

Sources and selection criteria

We searched PubMed for relevant articles by using the key words “fish,” “fish oils,” “omega 3 fatty acids,” and “cardiovascular disease.” References identified in the search are on bmj.com

Summary points

- Coronary heart disease is still the most common cause of death in the United Kingdom
- Omega 3 fatty acids from fish and fish oils can protect against coronary heart disease
- There is evidence to support the use of fish or fish oil supplements after myocardial infarction
- The mechanisms by which fish oils confer their benefits are not fully understood
- Unravelling these mechanisms may identify novel therapeutic targets and could help guide the development of future treatments for coronary heart disease
- Future trials may identify other patients who could benefit, such as those with stable angina, risk factors for coronary heart disease, or left ventricular dysfunction

Omega 3 polyunsaturated fatty acids

The association between omega 3 fatty acids and cardiovascular disease was established following the observation that the Greenland Inuit had low mortality from coronary heart disease despite a diet that is rich in fat. In the 1970s the Danish investigators Bang and Dyerberg proposed that this could be because of the high content of omega 3 fatty acid in the Inuit diet, which consisted largely of fish, seal, and whale (fig 1).
Fats and fatty acids

- Saturated fats: Animal fats, butter, lard
- Monounsaturated fats: Olive oil, Avocados, Peanuts, Almonds
- Polyunsaturated fats: Corn oil, Safflower oil, Sunflower oil
- Omega 3 fatty acids: Eicosapentanoic acid, Docosahexanoic acid
- Omega 6 fatty acids: Arachidonic acid, Docosapentanoic acid
- Omega 9 fatty acids: Linolenic acid

Omega 3 fatty acids, along with omega 6 fatty acids, are essential polyunsaturated fatty acids (fig 2 and fig 3). The Western diet is abundant in omega 6 fatty acids, mainly from vegetable oils rich in linoleic acid.

However, humans lack the necessary enzymes to convert omega 6 fatty acids to omega 3 fatty acids, and the latter must be obtained from separate dietary sources. While α-linolenic acid (ALA) is available from certain plants, eicosapentanoic acid (EPA) and docosahexanoic acid (DHA) are derived from fish and fish oils. This review is limited to the two marine derived omega 3 fatty acids.

Epidemiological and observational studies

Most studies have shown an inverse association between fish consumption and the risk of coronary heart disease. Furthermore, both consumption of fish and higher blood concentrations of omega 3 fatty acids are associated with a reduced risk of sudden death. However, some studies have not found a relation between intake of fish and coronary heart disease. These inconsistencies could be due to differences in methods, study populations, or fish. Importantly, most studies showing no association were in populations with an already moderate fish intake, potentially masking any relation. Overall, fish consumption seems to be beneficial, and a systematic review of 11 prospective cohort studies concluded that fish intake notably reduced mortality due to coronary heart disease in populations at increased risk.

Clinical intervention trials

Several trials have assessed the effects of fish and fish oil supplements on coronary heart disease, mainly after myocardial infarction (table 1). The diet and reinforcement trial (DART) randomised 2035 men with a recent myocardial infarction to three dietary interventions. Patients who received advice on fish had a relative reduction in total mortality of 29% during the two year follow up (P < 0.05), mainly because of a reduction in deaths from coronary heart disease. The open label Gruppo Italiano per lo Studio della Sopravvivenza nell’Infarto Miocardico Prevenzione (GISSI-Prevenzione) trial randomised 11 324 patients after myocardial infarction to either a daily capsule of about 850 mg omega 3 fatty acid, 300 mg vitamin E, both, or neither. After 3.5 years participants randomised to fish oil capsules had a reduction in relative risk of 15% in the composite primary end point of total mortality, non-fatal myocardial infarction, and stroke (P = 0.023). The relative risk of cardiovascular death was also reduced, by 30% (P = 0.024), and of sudden death by 45% (P = 0.01). These benefits were apparent within just four months of randomisation.

Two smaller secondary prevention trials have also assessed the effects of omega 3 fatty acids. In an Asian population patients with a suspected myocardial infarction randomised to fish oil capsules experienced a significant reduction in mortality from coronary heart disease after one year compared with placebo. However, a Norwegian study reported no benefit in patients after myocardial infarction who were given fish oil capsules compared with placebo after 1.5 years. This may have been because of the high habitual fish consumption among the general population in that area, with omega 3 supplementation conferring no additional benefit.

A recent trial of 3114 men with angina unexpectedly found that individuals advised to eat oily fish, and particularly those given fish oil capsules, had a higher risk of cardiac death than people not given advice to eat fish (11.5% v 9%, P = 0.02). The investigators speculated that this may have arisen from risk compensation or other changes in patients’ behaviour. Several flaws in this study weakened the validity of the results, and they should be viewed with caution until more evidence becomes available.

Clinical review
Mechanism of action

Although the weight of evidence outlined above supports a protective effect of omega 3 fatty acids on coronary heart disease, the mechanisms through which they confer these benefits remain unclear. Omega 3 fatty acids have several potentially cardioprotective effects (Box 1), although the relative contribution of each of these is not fully understood.

**Arrhythmias**

The benefits of fish oils were originally thought to be due to their antithrombotic effects, but recent evidence has indicated that the predominant effect may be antiarrhythmic. In the GISSI-Prevenzione trial the decrease in mortality was largely due to a reduction in sudden death, and, as in DART, no reduction in the rate of non-fatal myocardial infarction occurred. Fish oil supplementation increases heart rate variability in patients after myocardial infarction, which correlates with a lower risk of mortality and malignant arrhythmia. In animal models fish oil protects against ventricular fibrillation after surgical occlusion of a coronary artery. The addition of eicosapentanoic acid or docosahexaenoic acid can prevent or terminate pharmacologically induced arrhythmias in cultured cardiomyocytes from newborn rats. However, studies are necessary to show a direct antiarrhythmic effect in humans and trials are currently under way in patients with implantable defibrillators.

**Thrombosis**

Activation of platelets and their deposition at sites of unstable plaque rupture promotes thrombus formation, and these critical events have become a common therapeutic target in acute coronary syndromes. However, the effects of omega 3 fatty acids on platelet function and thrombosis are controversial. Large doses reduce platelet aggregation, but smaller amounts have modest platelet inhibitory effects. Omega 3 fatty acids have inconsistent effects on fibrinolysis and little effect on blood coagulability. Therefore, although omega 3 fatty acids have an antithrombotic effect, its relevance to the mortality reduction seen with lower doses is unclear.

**Atherosclerosis**

Omega 3 fatty acids may also influence the atherosclerotic process. Fish oil fed to experimental animals protects against progression of atherosclerotic plaques. In humans with coronary heart disease omega 3 fatty acid supplementation versus placebo for two years resulted in modest improvements in atherosclerosis as assessed by angiography. These effects may be due to a reduction in lipids, inflammation, production of growth factor, or suppression of smooth muscle cell proliferation. An important recent study randomised patients awaiting carotid endarterectomy to fish oil capsules, sunflower oil capsules, or control until surgery and then assessed morphology of the plaque. Omega 3 fatty acids were readily incorporated into atherosclerotic plaques in the fish oil group, and these plaques were more likely to have thick fibrous caps and less inflammatory infiltrate. These features imply a plaque that is less vulnerable to rupture and indicate that fish oils may be important in establishing stability of the plaque.

**Inflammation**

Inflammation has a central role in the development and progression of coronary artery disease. Omega 3 fatty acids are thought to decrease inflammation, providing a therapeutic target in acute coronary syndromes. However, the effects of omega 3 fatty acids on inflammation remain unclear. Studies have shown that fish oils may be important in establishing stability of the plaque.

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**Box 1: Possible mechanisms of action of omega 3 fatty acids**

- Antiarrhythmic
- Antithrombotic
- Antiatherosclerotic
- Anti-inflammatory
- Improves endothelial function
- Lowers blood pressure
- Lowers triglyceride concentrations

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**Table 1**

Effect of marine derived omega 3 fatty acids on death from coronary heart disease in secondary prevention of myocardial infarction

<table>
<thead>
<tr>
<th>Study</th>
<th>Design</th>
<th>Intervention</th>
<th>Absolute risk reduction (%)</th>
<th>Relative risk reduction (%)</th>
<th>No needed to treat</th>
<th>Comments</th>
</tr>
</thead>
<tbody>
<tr>
<td>Def and reinfection trial(^{15})</td>
<td>Randomised, controlled, two year follow up, 2033 men after myocardial infarction</td>
<td>Fish meal twice weekly or fish oil capsules if unable to tolerate fish (1.5 g/d)</td>
<td>7.7*</td>
<td>11.4</td>
<td>5.7</td>
<td>32.9</td>
</tr>
<tr>
<td>Indian experiment of infarct survival(^{15})</td>
<td>Randomised double-blind placebo controlled, one year follow up, 369 patients after myocardial infarction</td>
<td>Fish oil (EPA+DHA 1.8 g/d) or mustard seed oil (ALA 2.9 g/d)</td>
<td>11.4*</td>
<td>22</td>
<td>10.6</td>
<td>48.2</td>
</tr>
<tr>
<td>GISSI-Prevenzione trial, Italy(^{11})</td>
<td>Randomised, controlled, 3.5 year follow up, 11 324 patients after myocardial infarction</td>
<td>Fish oil (EPA+DHA 0.85 g/d)</td>
<td>4.8**</td>
<td>6.8</td>
<td>2</td>
<td>29.7</td>
</tr>
<tr>
<td>Nilsen et al(^{11})</td>
<td>Randomised double-blind placebo controlled, 1.5 year follow up, 309 patients after myocardial infarction</td>
<td>Fish oil (EPA+DHA 3.5 g/d)</td>
<td>5.3</td>
<td>5.3</td>
<td>—</td>
<td>—</td>
</tr>
</tbody>
</table>

\(^*P<0.01\) between control and intervention groups. \(^**P<0.004\) between control and intervention groups. EPA=eicosapentanoic acid, DHA=docosahexaenoic acid, ALA=\( \alpha \)-linolenic acid.
Eicosapentanoic acid

Omega 3 derived eicosanoids

These cellular mediators enhance platelet aggregation and are generally pro-inflammatory. Consumption of omega 3 fatty acids increases eicosapentanoic acid in the cell membrane. This competes with arachidonic acid for enzymatic conversion into its own metabolites, the omega 3 derived eicosanoids. These are less active and can partly oppose or antagonise the pro-inflammatory actions of the omega 6 eicosanoids.

Independent of the effects on the metabolism of eicosanoids fish oils suppress pro-inflammatory cytokines and reduce expression of cell adhesion molecules. These are critical in recruiting circulating leukocytes to the vascular endothelium, an important event in the pathogenesis of atherosclerosis and inflammation. These effects may be mediated through actions on intracellular signalling pathways, leading to reduced activation of transcription factors such as NF-κB. However, the precise effects of omega 3 fatty acids on these fundamental cellular processes and their potential impact on coronary heart disease are yet to be delineated completely.

Endothelial function

Abnormal endothelial function is found in individuals with cardiovascular risk factors or established coronary heart disease. Omega 3 fatty acids have direct effects on endothelial vasomotor function. Higher concentrations are associated with improved dilation of the brachial artery in young adults with cardiovascular risk factors, which implies a protective effect on endothelial function. In hyperlipidaemic men omega 3 fatty acid supplementation improved systemic arterial compliance and supplementation with docosahexanoic acid increased vasodilator responses in the human forearm.

Blood pressure

Fish oils can produce modest reductions in blood pressure, possibly through their effects on endothelial function discussed above. A recent meta-analysis of 36 randomised trials found a reduction in systolic blood pressure of 2.1 mm Hg and in diastolic blood pressure of 1.6 mm Hg. However, most trials used relatively high doses of fish oils (3.6 g/day), and the effects of lower intakes of omega 3 fatty acids, such as those in the secondary prevention trials, remain to be established.

Triglyceride lowering

Omega 3 fatty acids reduce triglyceride concentrations in a dose dependent manner, with intakes of about 4 g per day lowering serum triglycerides by 25-30%. Their effect on cholesterol is small and of uncertain clinical importance. Higher doses (3-5 g/day) can be used in the treatment of hypertriglyceridaemia.

Box 2: Recommendations for intake of omega 3 fatty acid

- Patients without documented coronary heart disease: Eat a variety of (preferably oily) fish at least twice weekly; Include oils and foods rich in α-linolenic acid
- Patients with documented coronary heart disease: Consume 1 g of eicosapentanoic and docosahexanoic acid daily, preferably from oily fish. Supplements could be considered in consultation with a doctor
- Patients with hypertriglyceridaemia: Take 2-4 g of eicosapentanoic acid and docosahexanoic acid daily, provided as capsules under a doctor’s care

These are the recommendations of the American Heart Association.

Box 3: Consumption and sources of marine derived omega 3 fatty acids

- Current consumption of marine derived omega 3 fatty acids is low, at 0.1-0.2 g/day. An expert US panel of nutrition scientists has recommended an intake of 0.05 g/day whereas the British Nutrition Foundation’s recommendation is 1.2 g/day
- Secondary prevention trials after myocardial infarction indicate that consumption of 0.5-1.8 g/day of eicosapentanoic and docosahexanoic acid from fish or fish oil supplements may be beneficial. Intake of marine derived omega 3 fatty acids can be increased through diet or with fish oil supplements. Oily fish such as mackerel, herring, tuna, salmon, sardines and trout are rich sources of eicosapentanoic and docosahexanoic acid (table 2), and two to three servings per week should provide approximately 1 g/day omega 3 fatty acids. Lean fish such as cod or haddock have smaller amounts, and fried fish (for example, from fast food establishments or frozen products) contains minimal amounts of omega 3 fatty acids.
- Concerns about the depletion of fish stocks will become more pressing if the benefits of fish oils are confirmed beyond the population after myocardial infarction, as this may result in an unsustainable increase in demand. Alternative strategies to increase omega 3 intake include supplementing animal feed with fish oil to augment the omega 3 content of eggs, meat, and milk. Available foods can also be enriched in eicosapentanoic and docosahexanoic acid, although they may impart a fishy aroma or flavour. A different approach independent of an adequate supply of fish oil would involve using modern biotechnology to genetically modify certain plants species, thereby producing plants and plant oils rich in eicosapentanoic and docosahexanoic acid.

Omega 6

Linoleic acid

Arachidonic acid

Cyclo-oxygenase

Pro-inflammatory

Omegas 6 derived eicosanoids

2 series prostanoids

TXA2, PGE2, PGD2

LTB4, LTC4, LTE4

4 series leukotrienes

5 series leukotrienes

Omegas 3 derived eicosanoids

3 series prostanoids

TXA3, PGE3, PGD3

LTB5, LTC5, LTE5

5 series leukotrienes

LTB5, LTC5, LTE5

Anti-inflammatory

Fig 4 Synthesis of eicosanoids from omega 6 and omega 3 fatty acids. Arachidonic acid and eicosapentanoic acid compete for the cyclo-oxygenase and lipoxygenase enzymes for conversion into eicosanoids. Those derived from arachidonic acid are pro-inflammatory and pro-aggregatory, whereas those derived from omega 3 fatty acids are anti-inflammatory and inhibit platelet aggregation.
Table 2 Content of omega 3 fatty acids of selected fish and seafood (adapted from the guidelines of the American Heart Association)

<table>
<thead>
<tr>
<th>Amount of fish (in g) required to provide 1 g EPA-DHA</th>
<th>EPA-DHA content (g) per 100 g serving of fish (edible portion)</th>
<th>EPA</th>
<th>DHA</th>
</tr>
</thead>
<tbody>
<tr>
<td>Tuna (fresh)</td>
<td>0.29-1.51</td>
<td>86</td>
<td>357</td>
</tr>
<tr>
<td>Atlantic salmon</td>
<td>1.29-2.15</td>
<td>42.5</td>
<td>70.9</td>
</tr>
<tr>
<td>Mackerel</td>
<td>0.4-1.85</td>
<td>54</td>
<td>250</td>
</tr>
<tr>
<td>Atlantic herring</td>
<td>2.01</td>
<td>50</td>
<td></td>
</tr>
<tr>
<td>Rainbow trout</td>
<td>1.15</td>
<td>87</td>
<td></td>
</tr>
<tr>
<td>Sardines</td>
<td>1.15-2</td>
<td>50-87</td>
<td></td>
</tr>
<tr>
<td>Albacore</td>
<td>0.47-1.18</td>
<td>85</td>
<td>213</td>
</tr>
<tr>
<td>Tuna (canned)</td>
<td>0.31</td>
<td>352</td>
<td></td>
</tr>
<tr>
<td>Cod</td>
<td>0.28</td>
<td>357</td>
<td></td>
</tr>
<tr>
<td>Haddock</td>
<td>0.24</td>
<td>417</td>
<td></td>
</tr>
<tr>
<td>Calfish</td>
<td>0.18</td>
<td>556</td>
<td></td>
</tr>
<tr>
<td>Flounder or sole</td>
<td>0.49</td>
<td>204</td>
<td></td>
</tr>
<tr>
<td>Oyster</td>
<td>0.84</td>
<td>227</td>
<td></td>
</tr>
<tr>
<td>Shrimp</td>
<td>0.32</td>
<td>375</td>
<td></td>
</tr>
<tr>
<td>Scallop</td>
<td>0.2</td>
<td>500</td>
<td></td>
</tr>
<tr>
<td>Cod liver oil capsule</td>
<td>0.19</td>
<td>5</td>
<td></td>
</tr>
<tr>
<td>Omacor (Pronova)</td>
<td>0.85</td>
<td>1</td>
<td></td>
</tr>
</tbody>
</table>

EPA=icosapentanoic acid, DHA=docosahexanoic acid.

Omega 3 content varies markedly depending on species, season, diet, and packaging and cooking methods, and the figures above are therefore rough estimates.

Clinical implications

Omega 3 fatty acids from fish or fish oil supplements should be considered in the secondary prevention regi-

men of patients after myocardial infarction. Patients should consume about 1 g/day of eicosapentanoic acid and docosahexanoic acid, preferably by increasing their intake of oily fish to at least two servings per week. Fish oil capsules may be considered for those unable to tolerate fish or change their diet effectively. Approved pharmaceutical grade capsules should be prescribed rather than encouraging over the counter supplements.

Recent guidelines from the American Heart Association (box 2) have gone further, supporting the use of fish oil supplements for patients with “documented” coronary heart disease. However, we believe that more evidence is required before considering fish oil supplements for patients with coronary heart disease outside the specific indication of myocardial infarction. Others have argued that fish oil supple-
ments should not be recommended routinely for patients after myocardial infarction until more definitive evidence is available.

No trial has assessed the effects of fish oils on risk of coronary heart disease in primary prevention, and therefore explicit recommendations for this group cannot be made currently. Such a trial may prove impractical in terms of the numbers required. However, on the basis of evidence from epidemiologi-

cal and observational studies the consumption of (preferably oily) fish at least twice weekly should be encouraged as part of a balanced diet. Box 3 and table 2 show current consumption and dietary sources of eicosapentanoic and docosahexanoic acid. Any recommendations regarding fish and fish oils should be balanced against safety issues. Side effects such as fishy aftertaste are uncommon, and gastro-

testinal upset is infrequent at moderate intakes. Some reports show that fish oil may worsen glycaemic control in diabetes, but two meta-analyses found no adverse effect. Furthermore, a recent prospective cohort study found that a higher consumption of omega 3 fatty acids was associated with a lower incidence of coronary heart disease and mortality in diabetic women. Concerns have been raised regarding adverse effects on low density lipoprotein (LDL) cholesterol and oxidative stress, but increases in LDL cholesterol are modest and studies into oxidative stress have been contradictory. Overall these effects are unlikely to be dominant given the apparent cardiac benefits of omega 3 fatty acids. More specific concerns regarding dietary fish relate to environmen-
tal contaminants, and a recent study showed that mercury in fish may attenuate their cardioprotective effects. Contaminants accumulate in larger, predaceous species and consumption of a variety of fish should minimise any possible adverse effects.

Future directions

Despite advances in our understanding of the cardio-
protective effects of fish oils in the past three decades, many issues remain unresolved. A double blind, placebo controlled trial of fish oil capsules in patients after myocardial infarction is required, and further trials are needed in individuals with risk factors for coronary heart disease or with heart failure. The specific effects of eicosapentanoic acid versus docosahexanoic acid on risk of coronary heart disease and the relative merits of oily fish compared with fish oil.
capsules also require further investigation. In addition to trials with clinical end points, research efforts should be focused on understanding the mechanisms by which fish oils might confer cardiac benefits. This will allow us not only to refine the clinical applications of ADF but hopefully also to identify other therapeutic targets and help guide the development of future treatments for coronary heart disease.

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