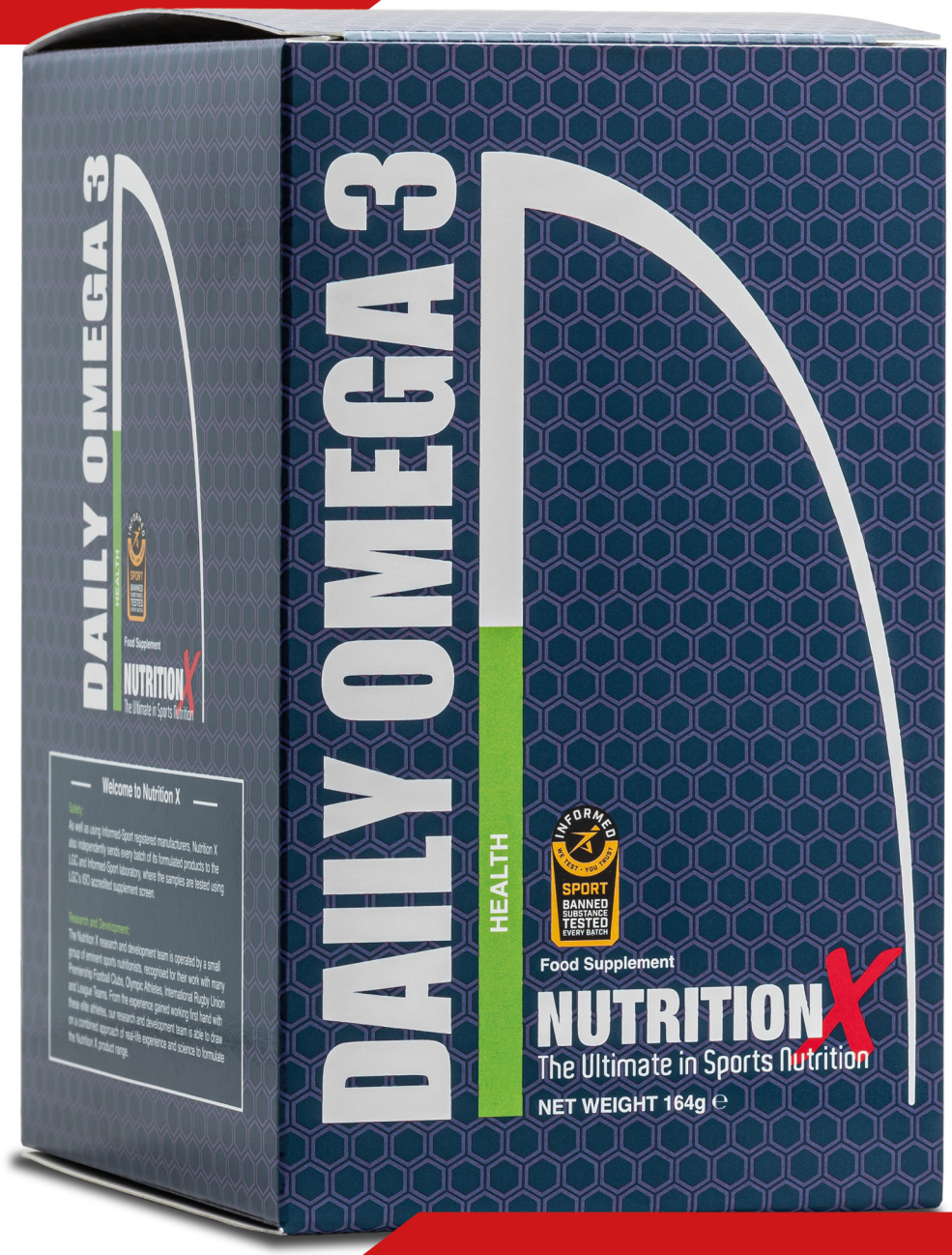
THE SCIENCE BEHIND



DAILY OMEGA 3

Omega-3 fatty acid/fish oils

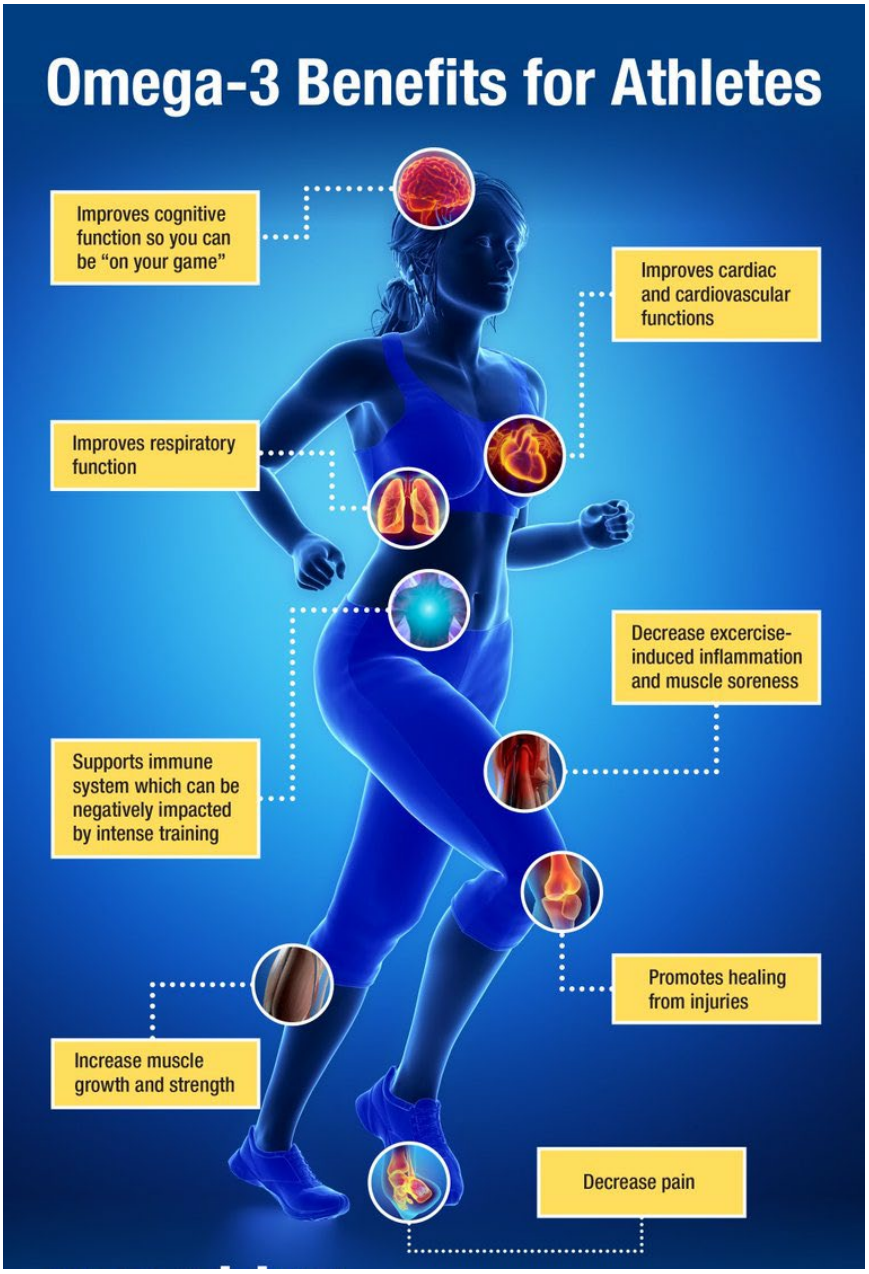


Figure 4. Likely benefits of omega-3 PUFAs and athletic performance

Practical application

NutritionX omega-3 fish oil capsules have high levels of DHA and EPA rather than ALA. Consequently, the capsules can be used as follows:

- **Normal dose (spring to autumn months) - 1-2 capsules per day.**
- **High dose (winter months) - 2-4 capsules per day.**
- **Heavy training periods - 2-4 capsules per day**
- **Recovery from injury/surgery - 1st week 1 capsule per day; thereafter 2-4 capsules per day**

The capsules may be taken at one time or split doses. The evening (after dinner) is preferable.

Introduction

Omega-3 polyunsaturated fatty acids (PUFAs) include α-linolenic acid (ALA), eicosapentaenoic acid (EPA), and docosahexaenoic acid (DHA). In the past few decades, many epidemiological studies have been conducted on the health benefits of omega-3 PUFAs. This article summarizes the structural features, properties, dietary sources, metabolism, and bioavailability of omega-3 PUFAs and their effects on health and exercise performance. Even though many health benefits of omega-3 PUFAs have been reported in the literature, there are also some controversies about their efficacy and certain benefits to human health.

Structure of Omega-3 fatty acids.

PUFAs include α-linolenic acid (ALA; 18:3), eicosapentaenoic acid (EPA; 20:5), and docosahexaenoic acid (DHA; 22:6), where the greater number reflects the number of carbon atoms and the smaller value the number of double bonds (Note – a fatty acid without any double bonds is a saturated fatty acid). Figure 1 illustrates the structure of selected PUFAs, and you will note that the omega-3 fatty acids have their first double bond 3 atoms away from their methyl terminus whereas the omega-6 fatty acids have their first double bond 6 atoms away from their methyl terminus. The key omega-3 PUFAs that are of interest to us are ALA, EPA, and DHA.

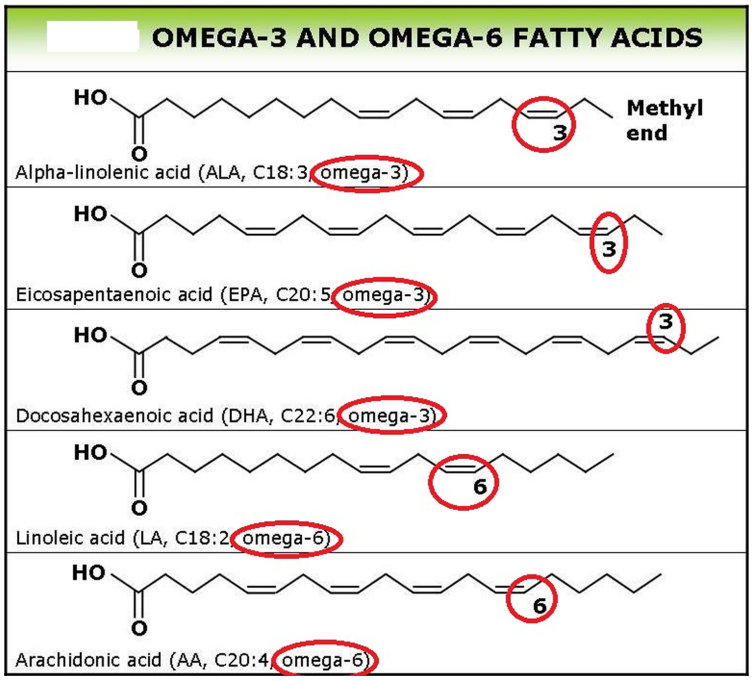


Figure 1. Basic structures of PUFAs – omega-3 and omega-6 fatty acids.

Oils containing these polyunsaturated fatty acids (PUFAs) originate primarily from certain plant sources (or are modified in plants), as well as in marine, algal, and single-cell sources. Long-chain PUFAs such as EPA and DHA (note these two PUFAs have 20 and 22 carbon atoms respectively compared with 18 carbon atoms for ALA) occur in the body lipid stores of fatty fish, the liver of white lean fish, and the blubber of marine mammals. Fish oils are sold as PUFA supplements as are plant seeds such as flax, chia, and canola – which are good sources of ALA, and serve as a precursor to the synthesis of PUFAs in the body. However, production of PUFAs from ALA in the body is limited to rates of less than 4%, hence incorporating PUFAs into the daily diet is important. According to many dietitians, the required ALA level should be between 1.1 and 1.6 g/day depending on age and gender. In addition, they also recommend the intake of at least two servings of fish per week, thus providing nearly 0.3–0.45 g of EPA and DHA per day. The Food and Agricultural Organization of the United Nations recommends 0.5–0.6% of total energy intake of ALA per day for the prevention of deficiency symptoms in adults, with a total PUFA intake of 0.5–2%.

The metabolic pathway of synthesis of omega-3 PUFAs from dietary ALA is shown in Figure 2. ALA is subsequently converted to the synthesis of EPA, and DHA.. Another major pathway involves the synthesis of omega-6 PUFAs from linoleic acid where arachidonic acid is the major end product. The metabolic pathway of omega-6 PUFAs from linoleic acid also employs the same enzymes as the

metabolic pathway of omega-3 PUFAs. Because the ALA levels are generally lower in the human diet than those of linoleic acid, plasma and cell levels of omega-6 PUFAs tend to be higher than those of omega-3 PUFAs. The conversion of ALA to EPA and DHA has been shown to be 8% and 4% respectively. These data are not too impressive, and so the need for omega-3 fatty acids in the form of EPA and DHA (rather than ALA) to be present in the diet.

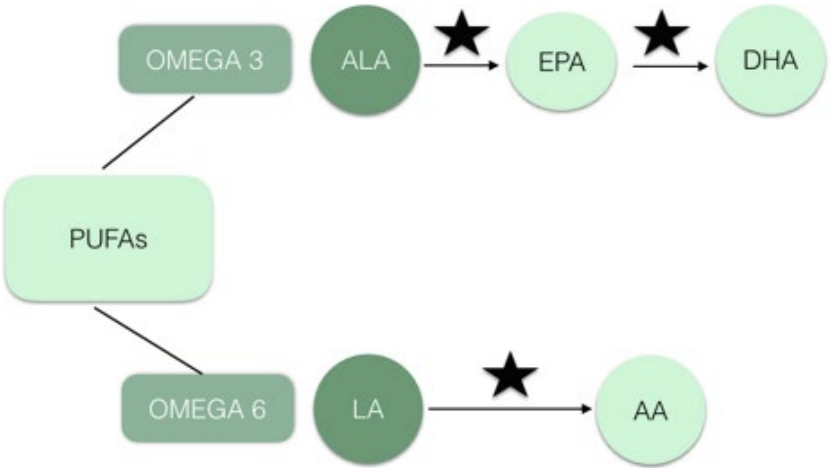


Figure 2. Schema of formation of omega-3 fatty acids from ALA and of omega-6 fatty acids (LA = linoleic acid; AA =arachidonic acid).

Dietary sources of omega-3 fatty acids

Omega-3 FAs are exclusively found in aquatic organisms and mainly originate in the liver of lean white fish such as cod and halibut, the body of oily fish such as mackerel, and salmon, and the blubber of marine mammals such as seals and whales. The major omega-3 FAs from marine sources are EPA and DHA. The primary source of ALA is plants, concentrated mainly in some seeds and nuts, and in some vegetable oils. Flaxseed, chia seeds, and walnuts are known to be good sources of ALA. EPA and DHA can be synthesized in the human body using ALA as a precursor. However, bioconversion of ALA to EPA and DHA is limited and so we require adequate dietary intake of these FAs. Table 1 illustrates the content of ALA, EPA and DHA in various food sources.

Table 1. Selected food items and omega-3 FA content.

Food Item	ALA (per 100gm serving for fish/seafood)	EPA (per 100gm serving for fish/seafood)	DHA (per 100gm serving for fish/seafood)	Saturated Fat (per 100gm serving for fish/seafood)	Cholesterol (per 100gm serving for fish/seafood)
Salmon, wild Atlantic (cooked)	–	411mg	1,429mg	1.26gm	71mg
Herring, Atlantic (cooked)	–	909mg	1,105mg	2.62gm	77mg
Salmon, sockeye (canned and drained, without skin and bones)	40mg	440mg	700mg	1.21gm	66mg
Mollusks, oyster, eastern, wild (cooked)	160mg	350mg	270mg	0.74gm	62mg
Halibut, Atlantic and Pacific (cooked)	–	91mg	374mg	0.35gm	60mg
Tuna, light (canned in water, drained)	–	30mg	200mg	0.21gm	36mg
Tilapia (cooked)	40mg	–	130mg	0.94gm	57mg
Cod, Pacific (cooked)	–	20mg	60mg	0.05gm	61mg
Shrimp, raw	–	30mg	30mg	0.1gm	161mg
Walnuts, English (1 oz)	2,542mg	–	–	1.7gm	–
Chia seeds (1 tbsp)	1,761mg	–	–	0.32gm	–
Flaxseed, ground (1 tbsp)	1,597mg	–	–	0.3gm	–
Navy beans (1 cup, cooked)	322mg	–	–	0.18gm	–
Pinto beans (1 cup, cooked)	234mg	–	–	0.23gm	–
Black beans (1 cup, cooked)	181mg	–	–	0.24gm	–
Collard greens (1 cup, cooked)	177mg	–	–	0.1gm	–
Spinach (1 cup, cooked)	166mg	–	–	0.1gm	–
Kale (1 cup, cooked)	134mg	–	–	0.1gm	–

Recommended Intakes

Dietary Reference Intake is the general term for a set of reference values used for planning and assessing nutrient intakes of healthy people. These values, which vary by age and sex, include:

- Recommended Dietary Allowance (RDA): Average daily level of intake sufficient to meet the nutrient requirements of nearly all (97%–98%) healthy individuals; often used to plan nutritionally adequate diets for individuals.

- Adequate Intake (AI): Intake at this level is assumed to ensure nutritional adequacy; established when evidence is insufficient to develop an RDA.
- Estimated Average Requirement (EAR): Average daily level of intake estimated to meet the requirements of 50% of healthy individuals; usually used to assess the nutrient intakes of groups of people and to plan nutritionally adequate diets for them; can also be used to assess the nutrient intakes of individuals.
- Tolerable Upper Intake Level (UL): Maximum daily intake unlikely to cause adverse health effects.

Currently there is insufficient data available to establish an EAR, although AIs have been established for all ages based on omega-3 intakes in healthy populations. Table 2 lists the current AIs for omega-3s in grams per day. There are no specific intake recommendations for EPA, DHA or other omega-3 FAs.

Table 2: Adequate Intakes (AIs) for Omega-3 FAs.

Age	Male	Female	Pregnancy	Lactation
Birth to 6 months*	0.5 g	0.5 g		
7–12 months*	0.5 g	0.5 g		
1–3 years**	0.7 g	0.7 g		
4–8 years**	0.9 g	0.9 g		
9–13 years**	1.2 g	1.0 g		
14–18 years**	1.6 g	1.1 g	1.4 g	1.3 g
19-50 years**	1.6 g	1.1 g	1.4 g	1.3 g
51+ years**	1.6 g	1.1 g		

*As total omega-3s
**As ALA

Omega-3 PUFAs and Health

The potential health benefits of consuming omega-3 FAs have been the focus of a great deal of scientific research. By far, the majority of research has focused on EPA and DHA from foods (e.g., fish) and/or dietary supplements (e.g., fish oil) as opposed to ALA from plant-based foods. Consequently, many observational studies link higher intakes of fish and other seafood with improved health outcomes.

Cardiovascular disease (CVD) and CVD risk factors

Many studies have assessed the effects of omega-3 PUFAs - primarily EPA and DHA on CVD and CVD risk factors, such as high blood pressure and elevated plasma lipids. This interest was spurred by epidemiological research dating back to the 1970s that found low rates of myocardial infarction and other coronary events among Greenland Inuit (Eskimos) and other fish-eating populations, such as the Japanese. Results from observational studies have been consistent with these findings, with several systematic reviews and meta-analyses showing that higher consumption of fish and higher dietary or plasma levels of omega-3 PUFAs are associated with a lower risk of heart failure (Djousse et al., 2012), coronary disease, and fatal coronary heart disease (Del Gobbo et al., 2016).

Early clinical trials supported the hypothesis that omega-3 FAs offer protection from CVD by reducing the heart's susceptibility to arrhythmias, lowering triglyceride levels, lowering blood pressure, and decreasing platelet aggregation(Kris-Etherton et al.,2002)). One of the first trials to point to a benefit of omega-3 FAs in the secondary prevention of heart disease was the Diet and Reinfarction Trial (Burr et al., 1989). In this study, 2,033 men under 70 years of age who had survived a myocardial infarction were randomly assigned to receive dietary advice about fat intake, fish intake, and/or dietary fibre intake or to receive no dietary advice. After 2 years, patients who were advised to consume at least two servings a week of fatty fish had a 29% reduction in all-cause mortality compared to those who did not receive this advice.

Supplementation with 1 g/day omega-3s (containing 850–882 mg EPA and DHA) for 3.5 years significantly reduced triglyceride levels and the risk of cardiovascular death and death from all causes compared to no treatment. A 1993 meta-analysis of 31 placebo-controlled trials also found that omega-3 PUFAs as fish oil modestly reduced systolic and diastolic blood pressure (Morris et al., 1993).

The authors of a systematic review that included six secondary-prevention and one primary-prevention trial of omega-3 supplementation published between 1966 and July 2005 concluded that consumption of omega-3 PUFAs from fish and fish oil supplements reduced rates of all-cause mortality, cardiac death, sudden death, and stroke (Wang et al., 2006). They noted that the evidence of benefit is stronger for secondary than for primary prevention.

So there are a plethora of findings alluding to the cardiovascular health benefits of using omega-3 PUFAs whether from an increase in fish consumption and/or supplementation. More recent studies

suggest a more complicated picture, especially with respect to omega-3s from supplements as opposed to food. Higher consumption of seafood, such as fatty fish, appears to provide protection from many adverse CVD outcomes. However, some studies have shown that taking omega-3 dietary supplements, such as fish oil supplements, might not provide the same protection. The issue with these investigations has been the dose provided and the amounts of DHA and EPA.

Overall, research indicates that consuming fish and other types of seafood as part of a balanced diet promotes heart health. Fish oil and other omega-3 supplements improve blood lipids and appear to reduce the risk of cardiac death. However, their effects on other cardiovascular endpoints are unclear and might vary based on dietary omega-3 intakes.

Figure 3 provides a schema highlighting some of the potential outcomes in relation to omega-3 FAs and cardiovascular health.

Rheumatoid arthritis and immune function

Rheumatoid arthritis (RA) is an autoimmune disease characterized by chronic inflammation of the joints. Its symptoms include pain, swelling, stiffness, and functional impairments. RA is typically treated with nonsteroidal anti-inflammatory drugs (NSAIDs), corticosteroids, and disease-modifying anti-rheumatic drugs. Due to their anti-inflammatory effects, some scientists hypothesize that omega-3 PUFAs reduce some of the symptoms of RA and patients' reliance on NSAIDs and corticosteroids.

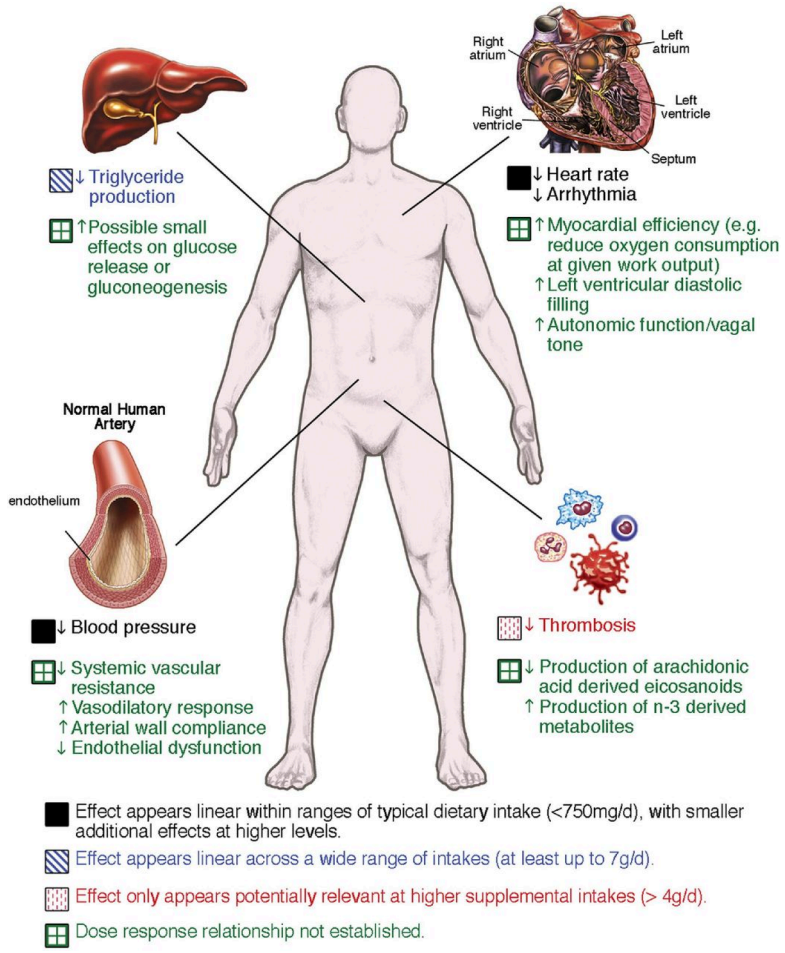


Figure 3. Potential factors in relation to omega-3 FAs and cardiovascular health.

Several clinical trials have examined the use of omega-3 supplementation in patients with RA. These trials have generally shown that omega-3 supplements reduce patients' use of anti-inflammatory drugs and corticosteroids, but that they do not have consistent effects on painful and/or tender joints, joint swelling, or morning stiffness. Reviews and meta-analyses of studies that assessed whether fish oil and omega-3 PUFAs are beneficial for RA have had inconsistent findings (Miles & Calder, 2012). Some suggest that they do not significantly affect the clinical symptoms of RA but do reduce the amounts of NSAIDs and corticosteroids required (Lee et al., 2012), whilst others indicate that omega-3 PUFAs reduce joint swelling and pain, morning stiffness, and number of painful joints in addition to reducing NSAID use (Goldberg & Katz, 2007). So the findings to date suggest that omega-3 PUFAs may be helpful as an adjunctive treatment to pharmacotherapy for ameliorating the symptoms of RA (Goldberg & Katz, 2007).

For those who wish to explore in greater detail the immune effects of omega-3 PUFAs, please see the review article by Calder (2017). Furthermore, If you are interested in reading how omega-3 PUFAs influence the gut bacteria and thereby enhance immune function (since the gut is a major immune tissue) , please feel free to read Constantini et al (2017). Figure 3 illustrates some key considerations about the role of omega-3 PUFAs on the gut and immune function.

Omega-3 PUFAs and Sport and Exercise

Omega-3 polyunsaturated fatty acids (PUFAs), such as DHA and EPA, are known for their anti-inflammatory properties as highlighted previously. However, what is less clear is whether they have a role in exercise performance. Oxidative stress occurs during exercise and while low levels are required for adaptation to training, chronic inflammation can tax the body's antioxidant systems. Strenuous exercise may lead to chronic inflammation. Omega-3 PUFAs are precursors to prostaglandins which are hormone-like compounds that help to reduce inflammation. Omega-3 PUFAs are thought to change the muscle cell membrane by affecting membrane fluidity, receptor function, and the production of cytokines, all of which lower the effect of exercise on muscle damage (Gammone et al., 2019)

The central and peripheral nerves contain PUFAs, with omega-3 PUFAs being key components of neurons, myelin, and muscle membranes. Supplementation with omega-3 PUFAs may improve nerve conduction and neuromuscular engagement, while also reducing exercise-induced inflammation (Lewis et al., 2015)

Ageing results in a loss of skeletal muscle mass (sarcopenia) and an increase in the production of reactive oxygen species (ROS) in the mitochondria of skeletal muscle cells thereby causing alterations to muscle fibers. Omega-3 PUFA supplementation, such as with fish oil, has been found to help lower blood markers of inflammation as well as mitigate delayed onset muscle soreness and muscle damage.

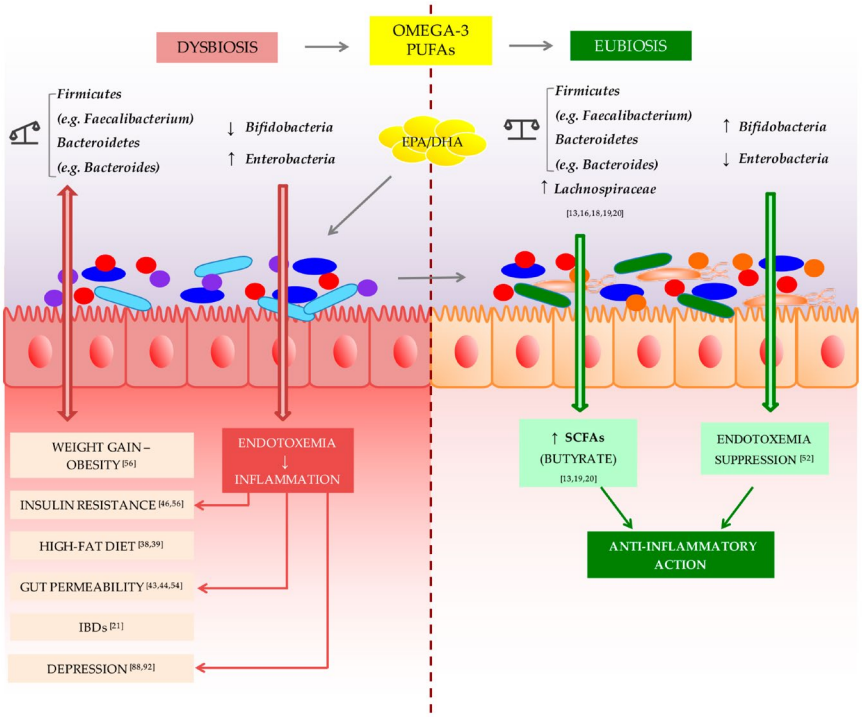


Figure 3. Omega-3 PUFAs and gut issues.

The benefit of omega-3 fatty acid supplementation for older adults is clearer than for younger, healthy athletes. PUFAs affect the cardiovascular and central nervous systems in older adults, which is largely why they may be so beneficial to pair with exercise. In adults with a history of myocardial infarction, or heart attack, DHA/EPA supplementation for 4 months has been shown to reduce and stabilize many of the post-exercise cardiovascular markers including heart rate recovery, stroke volume, and heart rate variability (Da Boit et al.,2017).

Studies have found improved quadricep strength as well as overall activation of skeletal muscle and force in postmenopausal and elderly women who couple exercise with omega-3 PUFA supplementation (Corder et al., 2016).

Endurance and prolonged intermittent activities

While there are benefits of omega-3 fatty acids for endurance training, they may not be significant enough to warrant supplementation solely for athletic performance. Omega-3 fatty acids act as a vasodilator, which helps increase the movement of oxygen into skeletal muscle during exercise (de Silva et al., 2016). In a study of adult rats, DHA supplementation led to improvement in endurance exercise capacity and mitochondrial function in skeletal muscle (Le Guen et al.,2015).

Endurance athletes may notice an improvement in muscle flexibility with EPA supplementation. In younger adult athletes, omega-3 supplementation can contribute to lower peak heart rate, reduce resting heart rate variability, and oxygen consumption required during exercise (Da Boit et al., 2017). Omega-3PUFA supplementation has also been shown to reduce oxygen consumption (Kawabata et al., 2014), heart rate (Peoples et al., 2008) and perceived exertion (Kawabata et al., 2014) during endurance exercise. The mechanism that underpins the improved oxygen efficiency with omega-3PUFA supplementation is unknown, although a potential mechanism that may underpin an alteration in the oxygen cost of exercise is through an increase in insulin sensitivity. Intuitively, an increase in insulin sensitivity would lead to greater muscle glycogen resynthesis and the subsequent potential to increase carbohydrate oxidation rate and decrease fat oxidation (Watt et al., 2002). During endurance exercise, a shift in substrate utilization from fat to carbohydrate would reduce the volume of oxygen used to meet demands for ATP resynthesis, and thereby improve the exercise efficiency (Philpott et al., 2019).

The initial 96 hours following exercise is commonly defined as the acute exercise recovery period. This period is considered crucial in optimising athlete performance, particularly during situations such as fixture congestion for team sport athletes. Repeated eccentric-based muscle contractions are known to cause damage to skeletal muscle fibres, and muscle damage has been shown to impair subsequent performance. There is biological rationale behind the notion that n-3PUFA has the potential to promote recovery from muscle

damaging exercise. In theory, n-3PUFA have the potential to protect the muscle from damaging exercise by increasing the structural integrity of the muscle cell membrane. Alternatively, n-3PUFA have the potential to accelerate the recovery process by exhibiting anti-inflammatory properties via several pathways. Therefore, it is intuitive that n-3PUFA supplementation could improve recovery following muscle damaging exercise either by preserving muscle membrane integrity or reducing other inflammatory agents.

A series of experimental studies have examined the influence of n-3PUFA ingestion on recovery from muscle damaging exercise and have revealed mixed results (Gray et al., 2014; Tsuchiya et al., 2016). A recent study examined the impact of acute supplementation with a high (15:1 ratio of EPA to DHA) or low (1.5:1 ratio of EPA to DHA) dose of n-3PUFA on exercise recovery (Jakeman et al., 2017). The exercise bout resulted in a reduced jump height, but the decrement in jump height was greater with the low-dose group. No differences in markers of muscle soreness and blood markers of muscle damage were observed. These data suggest that the high ratio of EPA to DHA may be the key factor in helping to maintain performance following acute supplementation and muscle damaging exercise.

More recently competitive soccer players were recruited to ingest either a combined omega-3PUFA (2.8 g/day), whey protein (30 g/day) and carbohydrate (20 g/day) supplement beverage, a whey protein (30 g/day) and carbohydrate (20 g/day) supplement beverage or a carbohydrate (24 g/day) only beverage over a 6 week period prior to performing an intense exercise bout (Philpott et al., 2019). In the 72 hours following the muscle damaging exercise, the soccer players in the omega-3PUFA plus protein group reported reduced levels of muscle soreness and also a reduction in plasma creatine kinase concentrations as a blood marker of muscle damage, compared to the whey protein beverage only, or the carbohydrate placebo beverage. As such, these data imply that omega-3PUFA supplementation protected the muscle cell from the muscle damage protocol and therefore soccer players experienced less damage during exercise. However, there was no influence of n-3PUFA ingestion on soccer performance tests such as the Yo-Yo intermittent recovery test or the Loughborough soccer passing test.

Recent research also has observed that four weeks of omega-3PUFA supplementation in soccer players resulted in improved anaerobic endurance running capacity while maintaining their habitual training schedule (Gravina et al., 2017). Over 4 weeks of training, soccer players experienced an increase of 203m in the Yo-Yo level 1 test following ingestion of 0.1 g/kg/day of n-3PUFA, compared

to only a 62 m improvement in the placebo group. However, adaptations in power, speed and maximal knee extensor strength were not influenced by the omega-3 supplementation.

Strength Training

Researchers have also explored the role of omega-3 fatty acid supplementation for strength training. Omega-3 supplementation improves nerve conduction, thereby influencing muscle activation (Lewis et al., 2015). Studies have shown that DHA/EPA supplementation before an eccentric bicep curl test leads to more repetitions, better range of motion, and lower levels of the inflammatory cytokine interleukin-6 (IL-6). Furthermore, loss of muscle strength and delayed onset muscle soreness three days after exercise were also decreased (Jouris et al., 2011; Tsuchiya et al., 2016). During a maximal back squat assessment, male athletes who supplemented with PUFAs experienced improved muscle activation and lower fatigue (Lewis et al., 2015), whilst males taking EPA supplements noticed better recovery than the placebo group after performing a plyometric squat jump test (Jakeman et al.,2017).

The primary metabolic driver of muscle hypertrophy is an increased stimulation of MPS in response to exercise and nutrition. Previous research has investigated the influence of n-3PUFA supplementation on acute measurements of muscle protein synthesis (MPS) and chronic measurements of changes in muscle mass and neuromuscular function. This line of research is based on the idea that n-3PUFA ingestion sensitises skeletal muscle to resistance exercise and protein ingestion. Consistent with this observation, research has demonstrated an increase in skeletal muscle omega-3 lipid content and stimulation of a key signalling protein that regulates MPS following four weeks of 5g/day n-3PUFA supplementation in active males (McGlory et al., 2014). The incorporation of omega-3PUFA into a muscle cell membrane has been observed, and such structural changes in membrane composition have been proposed to provide a mechanistic explanation for improvements in cell function with omega-3PUFA ingestion. Recent research suggests that a minimum supplementation period of 2 weeks is required to observe an increased incorporation of n-3PUFA into the muscle cell (McGlory et al., 2014). The incorporation of n-3PUFA into the muscle cell continues to increase after 4 weeks of supplementation, with no plateau observed. These data suggest that >4 weeks of omega-3PUFA supplementation is required to maximise muscle incorporation of n-3PUFA. There is mechanistic evidence from in vitro studies using muscle cell lines that EPA, rather than DHA, is the primary anabolic component of n-3PUFA (Kamolrat & Gray, 2013).

While MPS is the marker of muscle growth, a series of chronic intervention studies have directly measured changes in muscle growth or strength in response to a period of n-3PUFA supplementation. In a recent study, older adults underwent 6 months of either n-3PUFA (3.36 g/day EPA + DHA) or corn oil supplementation (Smith et al., 2015). Thigh muscle volume, handgrip strength and 1-RM strength all increased in the n-3PUFA group, whereas no changes were detected in placebo. However, there were no differences in body mass or body fat between the two conditions. Interestingly, only the thigh was measured for muscle volume. Given this increase in thigh muscle volume it was assumed that muscle mass was increased at the whole body level. Interestingly, no studies have measured the response of muscle growth or strength in response to omega-3PUFA supplementation in young adults or athletic populations.

The first study to measure muscle strength following a period of n-3PUFA supplementation observed an increase in peak torque with 90 or 150 days of omega-3PUFA supplementation at a dose of 2g/day (Rodacki et al., 2012). Training-induced improvements in neuromuscular function, such as muscle activation and electromechanical delay in various muscles including the bicep femoris and vastus lateralis were enhanced with omega-3PUFA.

Taken together, these data support a potential anabolic role for n-3PUFA ingestion in the context of preserving muscle mass in older adult populations. However, based on current information, there is limited information available to support an anabolic role of n-3PUFA for muscle growth in athletes.

Conclusion

The applications of n-3PUFA supplementation for sport performance are relevant to athletes from strength, endurance and team-based sports. Based on currently available scientific evidence, there is potential for n-3PUFA supplementation to improve muscle adaptation, energy metabolism, muscle recovery and injury prevention. As such, n-3PUFA supplementation for athletes should prove to be effective. At the very least the evidence suggests that increasing n-3PUFA in the diet or via a supplement will not be detrimental. However, more research is needed to further investigate these promising applications of n-3PUFA supplementation, particularly on skeletal muscle mass retention, growth, and adaptation. Figure 4 provides an overview of likely benefits of omega-3 PUFAs and performance.

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