Journal of Physical Education and Sport ® (JPES), Vol 20 (Supplement issue 4), Art 313 pp 2322 – 2329, 2020
online ISSN: 2247 - 806X; p-ISSN: 2247 – 8051; ISSN - L = 2247 - 8051 © JPES

Original Article

Effects of fish oil supplementation in the sport performance

STEFANIA D'ANGELO[1], GIUSEPPE MADONNA[2]
[1,2,]University of Naples "Parthenope", Naples, ITALY

Published online: August 31, 2020
(Accepted for publication: August 22, 2020)
DOI:10.7752/jpes.2020.s4313

Abstract
Fish oils originate from the tissues of oily fish. Sharks, swordfish, tilefish, and albacore tuna contain high levels of eicosapentaenoic acid (EPA) and docosahexaenoic acid (DHA), both forms of omega-3fatty acids. Some individuals take fish oil supplements to help attention deficit-hyperactivity disorder, and disorders related to the brain. Fish consumption and fish oil supplementation have been dubbed brain food because of the relationship between these omega-3 fatty acids and improvement in cognitive function. Fish oil supplementation has been shown to decrease blood triglyceride levels in both athletes and no athletes. Although fish oil and consumption of fish have been linked to prevention of a number of disorders and diseases, it is important to read the scientific literature to ascertain what benefits have been found and what benefits are anecdotal. Fish oil supplementation has recently been proposed as an ergogenic aid for athletes. This claim is mainly based on the mechanistic evidence that fish oil and then omega-3 polyunsaturated fatty acids exerts anti-inflammatory properties and acts to change the functional capacity of the muscle cell by changing the fluidity of the protein and lipid membrane within the cell membrane. This overview summarized the scientific data related to the effectiveness of fish oil supplementation to improve athlete performance in the context of muscle adaptation, energy metabolism, muscle recovery and injury prevention, is summarized. Based on the available information, only some scientific evidence proves that supplementation with fish oil can have a positive effect on spot performance; therefore, at present, it is not possible to conclude that the integration of fish oil is always effective and ergogenic.
Keywords: Fish oil, ω-3fatty acids, ω-3PUFA, omega-3, performance, supplementation.

Introduction

Exercise training exerts a physiologic stress on the body, which requires a coordinated response by the cardiovascular, pulmonary, and nervous systems to increase the blood flow and the oxygen supply to the working skeletal muscle. At rest, muscle receives approximately 20% of the total blood flow which, during exercise, this can increase to more than 80%. Physical exercise always causes, to varying degrees, a certain degree of mechanical and metabolic stress on the human body and this leads to two results: inflammation and oxidative stress.

In fact, the appearance of oxidative stress and its effects on the body can take place in certain pathological conditions (Cobley et al, 2018; Pizzino et al, 2017; D'Angelo et al, 2012a; D'Angelo et al, 2013; Ingrosso et al, 1995; Ingrosso et al, 1996), but it is also a consequence of competitive sports (Kawamura &Muraoka, 2018).

For this reason, interest in finding nutrients and supplements that can improve athletic performance, recovery and to also reduce the effects of oxidative stress is increasing (D'Angelo & Rosa, 2020).
Athletes often use dietary supplements in order to increase metabolic capacity, delay fatigue onset, improve muscle hypertrophy, and shorten recovery periods (D'Angelo &Cusano, 2020).

In recent times the concept of the presence, in daily consumption foods, of nutraceutical components is born; these are food components, called "functional", which provide important benefits for human health, not only in conservative terms, but above all preventive **(**D'Angelo & Tafuri, 2020; Deane et al., 2017; Motti et al., 2018; D'Angelo et al., 2019a; Meccariello et al., 2020**).** Many nutraceuticals are polyphenols, a major group of plant compounds chemically characterized by the presence of one or more aromatic rings with one or more hydroxyl substituents and the main foods rich in polyphenols are fruits and vegetables (D'Angelo et al., 2009; D'Angelo, 2020; D'Angelo & Rosa, 2020a). These phytochemicals possess anti-oxidant (Zappia et al., 2010; del Monacoet al., 2015; D'Angelo et al., 2007; D'Angelo et al., 2012b; D'Angelo &Sammartino, 2015) and anti-proliferative actions (D'Angelo et al., 2017; Martino et al., 2019; D'Angelo et al., 2019b; Boccellino et al, 2020), and also a wide range of beneficial effects against atherosclerosis, brain dysfunction, stroke, cardiovascular diseases, and cancer (Del Rio et al., 2013; D'Angelo 2020a; Boccellino& D'Angelo, 2020).

They can act as anti-inflammatories and antivirals, contributing to cell apoptosis, and numerous works offer them capable of improving sports performance (**Malaguti** et al., 2013).

Another functional food is fish oil, nutriment rich in ω3-polyunsaturated fatty acids (ω-3PUFA).

Corresponding Author: DAVIDE DI PALMA, E-mail: davide.dipalma@uniparthenope.it

Fish oil (FO) is one of the product development from fishery commodities which potential to be developed. The global usage of fish oil in 2002 is edible (14%), industrial (5%) and aquatic (81%).

Various studies in recent years have shown its beneficial effect on diverse mechanisms including anti-oxidant and anti-inflammatory effects. Because of the aforementioned properties over, the last decade there has also been an increasing interest in potential benefits of ω-3 PUFA supplementation in athletic populations, with an ultimate goal to improve athletic/sporting performance. The aim of the current review is to give an overview of the current literature which has investigated the effect of fish oil supplementation in athletic performance.

1. Fish oil composition

Fish oil is oil rich in fatty acids, both the ω-3 fatty acids docosahexaenoic acid (DHA, 22:6n-3) and eicosapentaenoic acid (EPA, 20:5n-3); they are polyunsaturated fatty acids (PUFA) with a double carbon bond starting after the third carbon atom from the end of the carbon chain (**Figure 1**). Fish, like men, are not able to directly synthesize omega-3 (ω-3), but accumulate them in their tissues by absorbing them from the microalgae or from the animals they eat. Photosynthesis by most algae and phytoplankton is associated with the production of ω-3PUFA. Herring, sardines and other large and small blue fish, cod, salmon and tuna are among the richest fish in ω-3 fatty acids. Once purified by molecular distillation, the product is eventually integrated with tocopherol and enclosed in capsules or gelatin pearls (Mozaffarian et al., 2006).

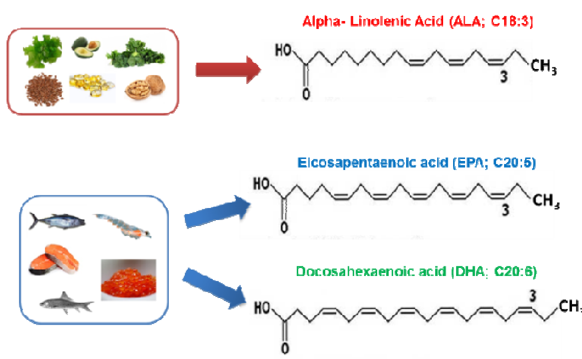

Figure 1.ω3-fatty acids and source.

Fish oil use in the food sector derives from the human body's need to take ω-3 polyunsaturated fatty acids from the outside, which it is unable to synthesize autonomously.

In reality, the ω-3PUFA family can be synthesized in the body starting from aω-3 precursor, alpha linolenic acid (ALA), particularly abundant in flax seeds and in many oil seeds such as walnuts, canola oil, soybean and hemp, and it is involved in important body functions. In the modern Western diet ω-3PUFA can be found in botanical sources, which are rich in ALA; and in marine sources, e.g. oily fish (e.g. salmon), crustacean (e.g. krill) and the liver of lean fish, which are rich in EPA, DHA and docosapentaenoic acid (DPA). ω-3PUFA are also frequently called 'essential' fatty acids, as they cannot be readily synthesized de novo by the body. These acids, members of the ω-linolenic family, eventually pass through the food web and are incorporated into fish lipids and, thus, form an integral part of our diet either through consumption of fish, fish oils or the flesh of terrestrial animals subjected to a diet containing fish or fish products.

2.Fish oil: propertiesand benefits

The effects of FO on health are mainly derived from its immune-modulatory and anti-inflammatory proprieties. Through these properties it has been demonstrated that ω-3PUFA supplementation may help in the prevention or treatment of many inflammatory-related diseases such as diabetes and cardiovascular disease (Dewailly et al., 2001; Hill et al., 2007).

Today many foods common to the Western diet are deficient in ω-3, but abundant in ω-6PUFAs, with a very high ω-6/ω-3 ratio. It is believed that this unbalanced relationship is associated with the modern prevalence of cardiovascular diseases, cancer, diabetes and neurodegenerative diseases, which affect millions of people around the world. Evidence indicates that dietary supplementation with ω-3PUFA may reduce the risk of these diseases. As a result, governmental and scientific organizations now recommend increased dietary intake of ω-3PUFA (Simopoulos, 2016; Endo &Arita, 2016).

Several experimental studies have shown that taking ω-3PUFA and improving the ω-6 and ω-3 ratio could modulate the immune and inflammatory response. The anti-inflammatory effects of FO are partly mediated by inhibition of the 5-lipoxygenase pathway in neutrophils and monocytes, inhibiting the function mediated by leukotriene B4 of leukotriene B5. Furthermore, ω-3 decreases interleukin IL-1 and IL-6 inhibits inflammation. Inflammation is characterized by an increase in prostaglandins, cytokines and other pro-inflammatory mediators. Oxygen reactive species produce peroxidation of phospholipid membranes and damage DNA and intracellular proteins. A diet rich in ω-3PUFA provides photo-protection and counteracts the risk of ultraviolet-induced skin cancers. In addition to modifying the production of eicosanoids, ω-3PUFA can also reduce the activation of the NF-KB pathway, reducing the production of inflammatory cytokines that contrast with ω-6 fatty acid, which is a well-known stimulator of NF-KB activity (Gammone et al., 2019).

Fish oil via their biological active compounds have antioxidant and anti-inflammatory properties and might ensure cardio-protective benefits, safeguard against metabolic conditions, lower carcinogenic risk, help in cognitive disorders, or aid in sarcopenia and frailty. Initially used mainly for its hypo-triglyceridemicproperties, fish oil has gainedover time and with many studiesa large and important role in the preventive and therapeutic field (**Figure 2**). Besides having a vast number of benefits, another advantage of fish oil supplementation is the virtually nonexistent side effect profile when the appropriate doses are administered.

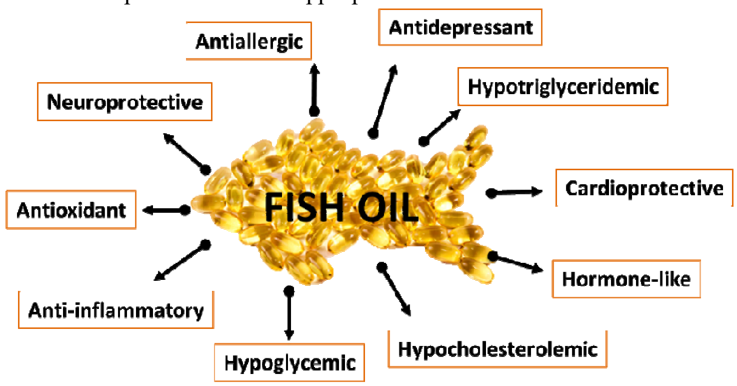

Figure 2. Possible effects of fish oil intake.

Short-term fish oil supplementation is associated with increasing the insulin sensitivity among those people with metabolic disorders (Gao et al., 2017). Numerous scientists have reported the various physiological functions of EPA and DHA including lipid metabolism, anti-inflammation, and cognitive function (Calder, 2015; Eslick et al., 2009; Jiao et al., 2014). An interesting possibility for depression therapy is fish oil, which contains several ω-3PUFA. For many years, the benefits of ω-3 fatty acids have been understood, since intervention for cardiovascular disease with these PUFAcaused the decreased production of VLDL. Furthermore, fish oil supplementation has also been shown to have antiplatelet activity, improve heart failure, improve vascular function in diabetics (Brinson et al., 2012), decrease selected markers of oxidative stress (Gray et al., 2014), decrease osteoarthritis associated knee pain (Peanpadungrat et al., 2015), improve outcomes in critically ill patients (especially acute lung injury/acute respiratory distress syndrome) (Glenn et al., 2014). Due to the many benefits and few adverse effects, fish oil supplementation is used for many ailments, including psychiatric disorders as depression (Mansoor et al., 2017).

The amount of studies concerning the preventive and therapeutic usefulness of fish oil has increased dramatically in the last years, thanks also to a refinement of study techniques. The certainty of these beneficial actions has been challenged by new discoveries. Particularly, recent studieshave failed to prove any associations between ω-3PUFAsupplementation and improvements in vascular diseases or diabetes (Derbyshire, 2018; Shahidi&Ambigaipalan, 2018). Therefore, the relationship between fish oil intakes and benefit (as cancer risk) is unclear: currently it appears to be controversial (Hanson et al., 2020).

In recent years,the fish oil has also been used successfully in sports.

3. Material and Methods

The databases PubMed and Web of Science were consulted. The combined keywordswere: "fish oil", "omega/ω-3", "exercise training", "inflammation", "oxidative stress", and "exercise performance". The search was carried out on January, 2010-June, 2020.

4. Results

Several studies suggest that intake of PUFA enhance the performance of skeletal locomotive muscles. In Atlantic salmon, for instance, dietary fatty acid composition and resulting changes in muscle lipid composition significantly affected maximum swimming speed. These effects were largely due to a positive relation between swimming speed and PUFA. Taken together, the data from animal studies suggest that ω-3PUFA may play a beneficial role in augmenting exercise performance (Shei et al., 2014).

Ergogenic aids can help prepare an individual to exercise, improve exercise efficiency, improve recovery from exercise or help prevent injury during intense training. In this regard, ω-3 has recently been considered an ergogenic supplement, which can play a role in these processes, which not only counteract the inflammation induced by exercise, but also improve muscle health and its availability of energy. The anti-inflammatory action of fish oil would prove useful in endurance athletes, who underwent training sessions or particularly intense competitions. In this context, FO could contribute to the prevention of neuro-muscle injuries related to intense exercise. The reduction of some markers of muscle damage, the greater ease of recovery and the reduction of the risk of injuries, would testify to the usefulness of FO in sports (Philpott et al., 2018). There is growing evidence that ω-3PUFApossess anabolic / anti-catabolic properties in skeletal muscle. The balance of muscle proteins is regulated by changes in the ratio of muscle protein synthesis (MPS): breakdown of muscle proteins (MPB). An increase in MPS or a decrease in MPB will lead to a positive balance and ultimately to hypertrophy. Muscle disuse due to illness or injury is associated with severe skeletal muscle loss. However, in some studies, a ω-3 supplementation action was shown to mitigate the loss of skeletal muscle mass. It is known that the increase in the availability of amino acids stimulates an increase in MPS and the integration of ω-3 can enhance the response to anabolic stimuli.A study concerning muscle recovery and soreness after performing eccentric biceps exercises showed that seven days of supplementation of 3 g/day ω-3PUFA decreased muscle damage and post-exercise pain (Jouris et al., 2011).

ω-3PUFA attenuated loss of muscle strength and gamma movement, blood inflammation markers such as TNF-α and markers of muscle damage, such as myoglobin, creatine kinase and troponin I in slow skeletal muscle. Furthermore, DHA appears to increase lipid oxidation and may stimulate glycolytic capacity in myocytes; ω-3PUFA can probably improve athletic performance, through a modulation on insulin sensitivity, which makes muscle cells more permeable as regards the necessary nutrients, such as glucose and amino acids (Gammone et al., 2019).

They can be recommended as a good supplement for athletic populations to improve some aspects of recovery during training or in competition.

Further long-term studies in humans are necessary to establish whether long-term ω-3 supplementation leads to muscle hypertrophy and the consequent functional gains. Furthermore, the question remains whether ω-3PUFA not only improve the MPS response to nutrition, but also increase MPS after an acute exercise of resistance exercise(Jeromson et al., 2015).

Fish oil supplementation has been shown to increase nerve conduction velocity in the elderly, modulate sarcolemma ion channel and improve cardiac contractile activity. Therefore, since the integration of fish oil improves both the contractility of the heart muscle and the speed of nerve conduction, it is reasonable to hypothesize that it may enhance the strength training effects on skeletal muscles. There is a lack of studies reporting the effects of fish oil supplementation on neuromuscular function in the elderly and the lack of information on the duration of supplementation and dose (Rodacki et al.,201).

There is evidence in humans that ω-3PUFA improve MPS response to nutrition and evidence from in vitro and rodent cancer models that supplementation with ω-3PUFA reduces muscle protein breakdown (Jeromson et al., 2015).

Long-chain ω-3 fatty acids help reduce the production of pro-inflammatory eicosanoids (such as interleukin-6) and promote the production of prostaglandins in the 1 series, which have an anti-inflammatory effect. The intense and frequent workouts that high-level athletes undergo determine an increased risk of accidents (in particular those of repeated micro-traumas and of muscular ones) due to a high production of pro-inflammatory molecules, often unbalanced by adequate production of anti-inflammatory molecules. Synergistically, EPA and DHA play a role in the resolution of inflammation through inflammatory mediators derived from EPA and DHA such as prostaglandins, leukotrienes, lipoxins, resolvins and proteins. The anti-inflammatory effect of EPA and DHA depends mainly on incorporation into phospholipids. EPA and DHA differentially alter the inflammatory response through specific lipid production of lipid mediators (Jeromson et al., 2015).

Integration with long-chain ω-3 can also be very useful in the prevention and treatment of anemia of the athlete, or a decrease in the amount of red blood cells (which carry oxygen in the blood) linked to iron deficiency: checking the status inflammation of the body facilitates the absorption and release of iron from the body's deposits. ω-3 fatty acids have also proved useful in improving the efficiency of the central nervous system, especially as regards reaction times and mood.

Preliminary findings demonstrate that fish oil may induce a physiological increase in testosterone synthesis and then fat supplements may influence physical performance. If fat supplements induce an increase in blood testosterone, this may have an effect on several other tissues, among which include stem or progenitor cells. Indirectly, fat supplements may have an effect on cardiac progenitor cells which are fundamental during heart development, myocardium homeostasis and myocardium regeneration. This consideration is very important taking into account that cardiovascular diseases are the leading causes of death among athletes (Macaluso et al., 2013).

Additional research on the effect of fish oil supplementation on enzymes leading to testosterone synthesis are important to clarify the molecular mechanisms by which fat supplements may contribute to increase the anabolic effect of exercise, and the side-effects of this kind of supplementation.

To date, no consensus has been reached on what constitutes an effective dose of ω-3PUFA, a question probably confused by individual variation and without apparent dose-response relationship. Previous studies have observed individual consumption of ω-3PUFA in tissues, therefore the same period of administration and the same dose can lead to different levels of ω-3PUFA tissue between subjects, potentially masking any effect of the increase in levels of ω-3PUFA fabric. Both the integration period and the duration of follow-up measures need to be taken into account, as these factors will influence the measurement of the results.

Unfortunately, not only drugs, but also nutritional supplements or nutraceuticals could have adverse effects. Despite the benefits listed above, there are potential risks associated with excessive use of ω-3PUFA. Important potential side effects include impaired platelet function. The presence of EPA and DHA leads to the production of thromboxane A3, which is a less potent platelet activator than thromboxane A2. Fish oil supplementation can therefore affect platelet activation due to the different eicosanoids produced, which leads to an antithrombotic effect that causes harmful effects for wound healing.

Physicians must understand the adverse effects that may occur with the integration of ω-3PUFA and that potential risks should be evaluated along with the potential benefits. Adverse effects are likely to be dose-dependent. In conclusion, it is necessary to understand the necessary dosages and the food concentration to aim for, when the integration of ω-3PUFA is recommended.

The diversity in testing protocols, dosages, subject population contributed to the heterogeneity of results from these studies, with several indicating a positive effect, but others demonstrating no effect. Although more studies demonstrated a positive effect of ω-3 fatty acids in relation to muscle damage and inflammation than compared to those with no effect, the relatively small number of studies is not a good indicator of the true relationship between ω-3 fatty acids, muscle damage, and inflammation. The mixed results from these human studies indicate that further investigation is warranted to identify the relationship between ω3-fatty acids, muscle damage, and the inflammatory response to exercise (Shei et al., 2014).

Fish oil significantly improved the lipid profile of active players randomized to treatment. These results suggest that FO supplementation is an effective way to increase EPA and DHA levels in plasma and should be considered as a method to improve modifiable cardiovascular risk lipid factors in professional football players (Yates et al., 2009).

It is also important to consider another aspect due to the integration of fish oil. Besides being oxidized, fatty acids also seem to be crucial signaling molecules for peroxisome proliferator-activated receptor signaling post-exercise, and thus for induction of the exercise-induced fatty acid oxidative gene adaptation program in skeletal muscle following exercise. Collectively, a high fatty acids turnover (guaranteed by a fish oil integration), in recovery seems essential to regain whole-body substrate homeostasis (Lundsgaard et al., 2020).However, ultimately, the effects in humans of fish oilsupplementation on muscle damage and inflammatory response to exercise, exercise metabolism, exercise and erythrocytesdeformability, and physical performance are not uniform. Differences in the exercise protocol and/or the muscle groups studied may have contributed to the differences in the findings between the different studies (Shei et al., 2014).Of course, the many variables do not allow for an unambiguous result.

Conclusions

The current overview shows that data regarding the effects of □-3PUFA supplementation are conflicting and we conclude that there is, therefore, not enough evidence supporting a beneficial role on the aforementioned aspects of exercise performance.

Although, a number of studies have assessed the efficacy of fish oil supplementation on red blood cell deformability, muscle damage, inflammation, and metabolism during exercise, only a few studies have evaluated the impact of fish oil supplementation on exercise performance. At present, it cannot conclude the hypothesis that fish oil supplementation is effective and ergogenic, and that the data is inconclusive whether fish oil supplementation effectively attenuates the inflammatory and immune-modulatory response to exercise. Future human studies should assess the effectiveness of fish oil supplementation on delayed onset muscle soreness, and subsequent exercise performance, in multisport athletes who typically engage in more than one bout of exercise per day using a more robust research design than those that have been used in previous studies.

References

Boccellino, M., & D'Angelo, S. (2020). Anti-Obesity Effects of Polyphenol Intake: Current Status and Future Possibilities.*International Journal of Molecular Sciences*, 21,5642. doi:10.3390/ijms21165642.

Boccellino, M., QuagliuoloL.,& D'Angelo S. (2020). Annurca Apple Biophenols' Effects in Combination with Cisplatin on A549 Cells.*Current Nutrition & Food Science*, 16, in press. doi:10.2174/1573401316999200504093028.

Brinson, B.E., & Miller, S. (2012). Fish oil: what is the role in cardiovascular health? *Journal of Pharmacy Practice*, 25(1): 69-74. doi: 10.1177/0897190011406983.

Burhani, M.D., &Rasenicka, M.M. (2017). Fish oil and depression: The skinny on fats. *Journal of Integrative Neuroscience*, 16(Suppl 1): S115–S124. doi: 10.3233/JIN-170072.

Calder, P.C. (2015). Marine omega-3 fatty acids and inflammatory processes: Effects, mechanisms and clinical relevance.*BiochimicaetBiophysicaActa*, 1851(4): 469-484.doi: 10.1016/j.bbalip.2014.08.010

Cobley, J.N., Fiorello, M.L., & Bailey, D.M. (2018).13 reasons why the brain is susceptible to oxidative stress.*Redox Biology*.doi: 10.1016/j.redox.2018.01.008.

D'Angelo, S., Cimmino, A., Raimo, M., Salvatore, A., Zappia, V., & Galletti P. (2007). Effect of reddening-ripening on the antioxidant activity of polyphenol extracts from cv. 'Annurca' apple fruits. *Journal of Agricultural and Food Chemistry*, 28; 55(24): 9977-9985. doi: 10.1021 / jf071773a.

D'Angelo, S.,Morana, A., Salvatore, A., Zappia, V., &Galletti, P. (2009).Protective effect of polyphenols from Glycyrrhizaglabra against oxidative stress in Caco-2 cells.*Journal of Medicinal Food*. 12(6):1326-1333.doi: 10.1089/jmf.2008.0285.

D'Angelo, S., Lembo, S., Flora, F., De Bonis, M.L., Balato, A., Ayala, F., Balato, N., Galletti, P., &Zappia, V. (2012a).Abnormal isoaspartyl residues in erythrocyte membranes from psoriatic patients.*Archives of Dermatological Research*, 304(6): 475-479. doi: 10.1007/s00403-012-1247-z.

D'Angelo, S., La Porta, R., Napolitano, M., Galletti, P., Quagliuolo, L., &Boccellino, M.R.(2012b). Effect of Annurca apple polyphenols on human HaCaT keratinocytes proliferation.*Journal of Medicinal Food*, 15(11):1024-1031. doi: 10.1089/jmf.2012.0076.

D'Angelo, S., Trojsi, F., Salvatore, A., Daniele, L., Raimo, M., Galletti, P., &Monsurrò, M.R.(2013). Accumulation of altered aspartyl residues in erythrocyte membraneproteins from patients with sporadic amyotrophic lateral sclerosis.*Neurochemistry International*,63 (6): 626-34.doi: 10.1016 / j.neuint.2013.09.006.

D'Angelo, S., &Sammartino, D. (2015). Protective Effect of *Annurca* Apple Extract Against Oxidative Damage in Human Erythrocytes. *CurrentNutrition&Food Science*, 2015. 11 (4):248-256. doi:10.2174 / 1573401311666150610210529

D'Angelo, S., Martino, E., Ilisso, C.P., Bagarolo, M.L., Porcelli, M. & Cacciapuoti, G. (2017). Pro-oxidant and pro-apoptotic activity of polyphenol extract from Annurca apple and its underlying mechanisms in human breast cancer cells.*International Journal of Oncology*, 51: 939-948. doi: 10.3892 / ijo.2017.4088.

D'Angelo, S., Scafuro, M., &Meccariello R. (2019)a. Possible adverse effects of BPA and nutraceuticals in endocrine functions. *Endocrine, Metabolic & Immune Disorders - Drug Targets*, 19 (5): 594-604. doi: 10.2174/1871530319666190101120119.

D'Angelo, S., Martino E., & Cacciapuoti, G. (2019) b. Effects of Annurca Apple (Malus pumila cv Annurca) Polyphenols on Breast Cancer Cells. *Current Nutrition & Food Science*, **15 (7):** 745-751.
doi:10.2174/1573401315666190206142025.

D'Angelo, S. & Cusano, P. (2020). Adherence to the Mediterranean diet in athletes.*Sport Science,* 13 (Suppl 1): 58-63.

D'Angelo, S. & Tafuri, D. (2020).Nutraceutical: their role in improving sports performance. *Sport Science*, 13 (Suppl1): 7-12.

D'Angelo, S. & Rosa, R. (2020). Oxidative stress and sport performance. *Sport Science*. 13 (Suppl 1): 18-22.

D'Angelo S. & Rosa R. (2020)a. The impact of supplementation with Pomegranate fruit (Punica Granatum L.) on sport performance.*Sport Science,*13 (Suppl 1): 29-37.

D'Angelo S. (2020). Polyphenols: Potential beneficial effects of these phytochemicals in athletes. *Current Sports Medicine Reports*. 19, 7, 260-265.doi: 10.1249/JSR.0000000000000729.

D'Angelo S. (2020)a. Current Evidence on the Effect of Dietary Polyphenols Intake on Brain Health. *Current Nutrition & Food Science,* 16, 8, 286-299, in press. doi:10.2174/1573401316999200714160126.

Deane, C.S., Wilkinson, D.J., Phillips, B.E., Smith, K., Etheridge, T., & Atherton P.J. (2017)."Nutraceuticals" in relation to human skeletal muscle and exercise.*American Journal of Physiology-Endocrinology and Metabolism*, 312(4), pp. E282-E299.doi: 10.1152/ajpendo.00230.2016.

Derbyshire, E. (2018) Brain Health across the Lifespan: A Systematic Review on the Role of Omega-3 Fatty Acid Supplements. *Nutrients*, 10(8): 1094. doi: 10.3390/nu10081094

Dewailly, E.E., Blanchet, C., Gingras, S., Lemieux, S., Sauve, L., Bergeron, J., &Holub, B.J. (2001). Relations between n-3 fatty acid status and cardiovascular disease risk factors among Quebecers. *The American Journal of ClinicalNutrition*, 74: 603–611. doi: 10.1093/ajcn/74.5.603.

del Monaco, G., Officioso, A., D'Angelo, S., La Cara, F., Ionata,E., Marcolongo, L., Squillaci, G., Maurelli, L., Morana, A. (2015).Characterization of extra virgin olive oils produced with typical Italian varieties by their phenolic profile. *Food Chemistry*, 184: 220–228. doi: 10.1016/j.foodchem.2015.03.071

Del Rio, D., Rodriguez-Mateos, A., Spencer, J.P., Tognolini, M., Borges, G., & Crozier A. (2013).Dietary (poly) phenolics in human health: Structures, bioavailability, and evidence of protective effects against chronic diseases. *Antioxidants & Redox Signaling*, 18(14): 1818-1892.doi: 10.1089/ars.2012.4581.

Endo, J., &Arita, M. (2016).Cardioprotective mechanism of omega-3 polyunsaturated fatty acids.*Journal of Cardiology*, 67: 22–27. doi:10.1016/j.jjcc.2015.08.002.

Eslick, G.D., Howe, P.R., Smith, C., Priest, R., &Bensoussan, A. (2009).Benefits of fish oil supplementation in hyperlipidemia: a systematic review and meta-analysis.*International Journal of Cardiology*, 136(1):4-16. doi: 10.1016/j.ijcard.2008.03.092.

Gammone, M.A., Riccioni, G., Parrinello, G., &D'Orazio, N. (2019).Omega-3 Polyunsaturated Fatty Acids: Benefits and Endpoints in Sport. *Nutrients*, 11(46): 1-16.doi: 10.3390/nu11010046.

Gao, H., Geng, T., Huang, T., &Zhaocorresponding, Q. (2017). Fish oil supplementation and insulin sensitivity: a systematic review and meta-analysis. *Lipids in Health and Disease*, 16: 131. doi: 10.1186/s12944-017-0528-0.

Glenn, J.O., &Wischmeyer, P.E. (2014). Enteral fish oil in critical illness: perspectives and systematic review. *Current Opinion in Clinical Nutrition & Metabolic Care*, 17(2):116-23. doi: 10.1097/MCO.0000000000000039.

Gray, P., Chappell, A., Jenkinson, A.M., Thies, F., & Gray, S.R. (2014). Fish oil supplementation reduces markers of oxidative stress but not muscle soreness after eccentric exercise. *International Journal of Sport Nutrition and Exercise Metabolism*, 24(2): 206-214. doi: 10.1123/ijsnem.2013-0081.

Hanson, S., Thorpe, G., Winstanley, L., Abdelhamid, A.S., & Hooper, L. (2020). PUFAH group Omega-3, omega-6 and total dietary polyunsaturated fat on cancer incidence: systematic review and meta-analysis of randomised trials. *British Journal of Cancer*, 29. doi.org/10.1038/s41416-020-0761-6.

Hill, A.M., Worthley, C., Murphy, K.J., Buckley, J.D., Ferrante, A., & Howe, P.R. (2007).n-3 Fatty acid supplementation and regular moderate exercise: Differential effects of a combined intervention on neutrophil function. *British Journal of Nutrition*, 98:300–309. doi: 10.1017/S0007114507707286.

Ingrosso, D., D'Angelo, S., Perna, A.F., Iolascon, A., Miraglia del Giudice, E. Perrotta, S., Zappia, V., & Galletti P. (1995). Increased membrane-protein methylation in hereditary spherocytosis.A marker of cytoskeletal disarray. European Journal of Biochemistry (The FEBS Journal), 228, 894-898. doi: 10.1111 / j.1432-1033.1995.0894m.x.

Ingrosso, D., D'Angelo, S., Perrotta, S., d'Urzo, G., Iolascon, A., Perna, A.F., Galletti, P., Zappia, V. & Miraglia del Giudice, E. (1996). Cytoskeletal behaviour in Spectrin and Band 3 deficient spherocytic red cells: evidence for a differentiated splenic conditioning role. British Journal of Haematology, 93, 38-41. doi: 10.1046 / j.1365-2141.1996.451990.x.

Jiao, J., Li, Q., Chu, J., Zeng, W., Yang, M., & Zhu, S. (2014). Effect of n-3 PUFA supplementation on cognitive function throughout the life span from infancy to old age: a systematic review and meta-analysis of randomized controlled trials. *The American Journal of Clinical Nutrition*. 100(6): 1422-1436.doi: 10.3945/ajcn.114.095315.

Jeromson, S., Gallagher, I.J., Galloway, S.D., & Hamilton, D.L. (2015).Omega-3 Fatty Acids and Skeletal Muscle Health.*Marine Drugs*,13(11): 6977-7004. doi: 10.3390/md13116977.

Jouris, K.B., McDaniel, J.L., &Weiss, E.P. (2011).The effect of n-3 PUFA fatty acid supplementation on the inflammatory response to eccentric strength exercise.*Journal of Science and Medicine in Sport,* 10: 432–438.

Kawamura, T., &Muraoka, I. (2018).Exercise-induced oxidative stress and the effects of antioxidant intake from a physiological viewpoint.*Antioxidants (Base),* 7(9): pii: E119. doi: 10.3390/antiox7090119.

Lundsgaard, A-M., Fritzen, A.M.,&Bente, K. (2020).The Importance of Fatty Acids as Nutrients during Post-Exercise Recovery.*Nutrients*, 12, 280.doi:10.3390/nu12020280.

Macaluso, F., Barone, R., Catanese, P., Carin, F., Rizzuto, L., Farina, F.,&Di Felice, V. (2013).Do Fat Supplements Increase Physical Performance? *Nutrients*, 5, 509-524; doi:10.3390/nu5020509.

Malaguti, M., Angeloni, C., &Hrelia, S. (2013). Polyphenols in exercise performance and prevention of exercise-induced muscle damage.*Oxidative Medicine and Cellular Longevity*, 2013, 825928. doi: 10.1155/2013/825928.

Martino, E., Vuoso, D.C., D'Angelo, S., Mele, L., D'Onofrio, N., Porcelli, M., & Cacciapuoti, G. (2019). Annurca apple polyphenol extract selectively kills MDA-MB-231 cells through ROS generation, sustained JNK activation and cell growth and survival inhibition. *Scientific Reports,* 10 (1):13045.doi: 10.1038/s41598-019-49631-x.

Meccariello, R., Santoro, A., D'Angelo, S., Morrone, R., Fasano, S., Viggiano, A., &Pierantoni, R. (2020). The Epigenetics of the Endocannabinoid System.*International Journal of Molecular Sciences*, 21(3): 1113. Doi:10.3390/ijms21031113

Motti, M.L., D'Angelo, S., &Meccariello, R. (2018). MicroRNAs, Cancer and Diet: Facts and New Exciting Perspectives. *Current Molecular Pharmacology*, 11(2): 90-96. doi:10.2174/1874467210666171013123733.

Mozaffarian, D., &Rimm, E.B. (2006).Fish intake, contaminants, and human health: evaluating the risks and the benefits. *JAMA*, 296(15):1885–1899.doi: 10.1001/jama.296.15.1885.

Peanpadungrat, P. (2015). Efficacy and safety of fish oil in treatment of knee osteoarthritis.*Journal of the Medical Association of Thailand*, 98 Suppl 3: S110–S114.

Philpott, J.D., Witard, O.C.,& Galloway, S.D.R. (2018).Applications of omega-3 polyunsaturated fatty acid supplementation for sport performance.*Research in Sports Medicine*. doi:10.1080/15438627.2018.1550401

Pizzino, G., Irrera, N., Cucinotta, M., Pallio, G., Mannino, F., Arcoraci, V., Squadrito, F., Altavilla, D., & Bitto, A. (2017). Oxidative Stress: Harms and Benefits for Human Health. *Oxidative Medicine and Cellular Longevity*, 2017: 8416763. doi: 10.1155/2017/8416763.

Rodacki,C.L., Rodacki A.L., Pereira, G., Naliwaiko, K., Coelho, I., Pequito, D., &Fernandes, L.C. (2012). Fish-oil supplementation enhances the effects of strength training in elderly women. The *American Journal of Clinical Nutrition*, 95(2): 428-36.doi: 10.3945/ajcn.111.021915.

Shahidi, F.,&Ambigaipalan, P. (2018).Omega-3 Polyunsaturated Fatty Acids and Their Health Benefits.*Annual Review of Food Science and Technology*, 9: 345-381. doi: 10.1146/annurev-food-111317-095850.

Shei, R.J., Lindley, M.R., &Mickleborough T.D. (2014).Omega-3 polyunsaturated fatty acids in the optimization of physical performance.*Military Medicine*, 179.144–156.doi: 10.7205/MILMED-D-14-00160.

Simopoulos, A.P. (2016). An Increase in the Omega-6/Omega-3 Fatty Acid Ratio Increases the Risk for Obesity. *Nutrients*,8, 128; doi:10.3390/nu8030128.

Vuoso D.C., Porcelli M., Cacciapuoti G., & D'Angelo S. (2020). Biological activity of MelAnnurca flesh apple biophenols. *Current Nutrition & Food Science*, 16, 8, *in press*. doi: 10.2174/1573401316666200217113808.

Yates, A., Norwig, J., Maroon, J.C., Bost, J., Bradley, J.P., Duca, M., Wecht, D.A., Grove, R., Iso, A., Cobb, I., Ross, N., &Borden, M. (2009).Evaluation of Lipid Profiles and the Use of Omega-3 Essential Fatty Acid in Professional Football Players.*Sport Health,* 1(1):21-30. doi:10.1177/1941738108326978.

Zappia, V., Galletti, P., Manna, C., D'Angelo, S., Napoli, D., De Bonis,M.L.,&Capasso, G. (2010). *Effects of Hydroxytyrosol on Cyclosporine Nephrotoxicity*. In: Victor R. Preedy and Ronald Ross Watson, editors, Olives and Olive Oil in Health and Disease Prevention. Oxford: Academic Press, (pp. 1245-1252). doi.org/10.1016/B978-0-12-374420-3.00136-4