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Research article

The effect of omega-3 fatty acid supplementation on the inflammatory response to eccentric strength exercise

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Abstract
Omega-3 fatty acids (omega-3) have anti-inflammatory properties. However, it is not known if omega-3 supplementation attenuates exercise-induced inflammation. We tested the hypothesis that omega-3 supplementation reduces inflammation that is induced by eccentric arm curl exercise. Healthy adult men and women (n=11; 35±10 y) performed eccentric biceps curls on two occasions, once after 14d of dietary omega-3 restriction (control trial) and again after 7d of 3,000 mg/d omega-3 supplementation (omega-3 trial). Before and 48 h after eccentric exercise, signs of inflammation was assessed by measuring soreness ratings, swelling (arm circumference and arm volume), and temperature (infrared skin sensor). Arm soreness increased ($p < 0.0001$) in response to eccentric exercise; the magnitude of increase in soreness was 15% less in the omega-3 trial ($p = 0.004$). Arm circumference increased after eccentric exercise in the control trial ($p = 0.01$) but not in the omega-3 trial ($p = 0.15$). However, there was no difference between trials ($p = 0.45$). Arm volume and skin temperature did not change in response to eccentric exercise in either trial. These findings suggest that omega-3 supplementation decreases soreness, as a marker of inflammation, after eccentric exercise. Based on these findings, omega-3 supplementation could provide benefits by minimizing post-exercise soreness and thereby facilitate exercise training in individuals ranging from athletes undergoing heavy conditioning to sedentary subjects or patients who are starting exercise programs or medical treatments such as physical therapy or cardiac rehabilitation.

Key words: Fish oil, muscle soreness, eicosapentaenoic acid, docosahexaenoic acid

Introduction

Omega-3 fatty acids are essential in the human diet, as there is no mechanism in humans for producing these fats from other substances. Omega-3 fatty acids serve as precursors to prostaglandins, which are powerful hormone--like substances that reduce inflammation and improve blood flow (Calder, 2006). For example, prostaglandin E3, which is produced from dietary omega-3 fatty acids, decreases swelling, reduces sensitivity to pain, and lessens the recruitment of inflammatory white blood cells (Maroon and Bost, 2006a). In addition, when humans ingest the omega-3 fatty acids, eicosapentaenoic acid (EPA) and docosahexaenoic acid (DHA), there is a decrease in both the production of thromboxane A2, a potent platelet aggregator and vasoconstrictor, and leukotriene B4 formation, an inducer of inflammation (Weber et al., 1986).

In light of the well-known involvement of omega-3 in the biology of inflammation, it is not surprising that more than 7,000 scientific studies, including 900 human clinical trials, have provided evidence supporting the effectiveness of fish oil and omega-3 fatty acids in the prevention and treatment for inflammatory conditions (Maroon and Bost 2006a). For example, omega-3 supplementation has been found effective for treating rheumatoid arthritis (Cleland et al., 2003; Kremer et al., 1990; Lau et al., 1993;Volker et al., 2000), osteoarthritis (Curtis et al. 2002), inflammatory bowel disease, Crohn's disease, ulcerative colitis (Kim, 1996; Ross, 1993; Salomon et al., 1990; Stenson et al., 1992), and psoriasis (Bittiner et al., 1988; Kojima et al., 1989). Despite the extensive literature on the effect of omega-3 supplementation on inflammatory disease conditions, no studies have assessed the effects of omega-3 supplements on the inflammatory responses to exercise. The potential implications of reducing post-exercise inflammation would be reduced pain and quicker recovery time from intense exercise.

The purpose of the present study was to determine if one week of omega-3 supplementation reduces clinical markers of localized inflammation as measured 48 hours after eccentric arm curl exercise. As localized inflammation is characterized by pain, swelling, and increased temperature, we hypothesized that omega-3 supplementation attenuates the increases in subjective ratings of muscle soreness, arm circumference and volume (as indices of swelling), and skin temperature.

Methods

Study design

This study was a repeated measures intervention trial in which subjects were assessed for inflammatory responses to eccentric exercise on two occasions: once after 14 days on a low omega-3 fatty acid diet (control trial) and again after seven days of omega-3 fatty acid supplementation (omega-3 trial). The participants reported to the laboratory on 5 occasions. During the first visit, a muscular strength test was conducted to determine 1-repetition maximum (1RM) weight for both arms. The study dietitian provided diet instructions pertaining to a restricted omega-3 diet and participants immediately started the diet and continued it throughout their involvement in the study. During the control trial, which was conducted after 14 days on the omega-3 restricted diet, the participants underwent baseline assessments of signs of inflammation, performed unilateral eccentric biceps curls to induce inflammation, and returned for follow-up measures of inflammation signs 48 h after eccentric exercise. During the

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omega-3 trial, which was conducted after 7 d of omega-3 supplementation, the participants underwent baseline assessments of inflammation signs, performed eccentric biceps curls using the contralateral arm, and returned for follow-up measures 48 h after eccentric exercise. The pairing of treatment conditions (control vs. omega-3) with arm dominance (dominant arm vs. non-dominant arm) was counterbalanced, such that half of the participants underwent the control trial using their dominant arm followed by the omega-3 trial with the non-dominant arm. The remaining half of the participants used the non-dominant arm for the control trial and the dominant arm for the omega-3 trial.

Subjects

Eleven healthy, 18- to 60-year old men (n = 3) and women (n = 8) were recruited from the Saint Louis, Missouri metropolitan area. Candidates for the study were excluded if they had allergies to fish or fish oil, or a self--reported history of diabetes, cardiovascular disease, significant pulmonary disease, hypertension, malignancy, musculoskeletal problems, or clotting disorders. In addition, candidates were excluded if currently taking non-steroidal anti-inflammatory drugs, aspirin or anticoagulants. All participants gave their informed written consent to participate in the study, which was approved by the Institutional Review Board at Saint Louis University.

Procedures

Dietary and exercise control: To minimize the possibility of diet and exercise habits confounding the results, the participants were instructed to keep a 2 d food diary and exercise journal during the control trial and to use this information to replicate their diet and exercise during the subsequent omega-3 trial. Additionally, the participants were instructed to refrain from stretching their arms to overcome the soreness induced by the eccentric exercise.

Strength assessment: Muscular strength (1RM) for preacher bench bicep curls was estimated for each arm individually by using the 1RM Berger Prediction table (Berger 1961). Prior to the strength assessment on each arm, the subject was allowed to practice the arm curl exercise for 3-5 repetitions with a light (2.3 kg) dumbbell. Then, the subject selected a dumbbell weight so at least one repetition could be performed, but no more than 15 repetitions before reaching fatigue. The subject then performed as many complete repetitions as possible. The number of repetitions and the weight were used to predict 1RM based on the Berger Prediction Table (Berger 1961).

Eccentric exercise: The goal of the exercise intervention was to induce bicep inflammation and soreness to a degree where change could be measured 48 hours post exercise. Eccentric exercise, especially for the elbow flexors, is a safe and commonly used means for experimentally inducing muscle inflammation (Friden and Lieber, 1992; Hirose et al., 2004; Nosaka and Clarkson, 1996; Trappe et al., 2001). Using 120% of the subject's 1-RM, two sets of eccentric biceps curls were performed on a preacher bench, with 60 s of rest between sets. During each repetition, the technician lifted the weight for the subject to the fully flexed elbow position, while the subject lowered the weight over a 4 s period until the elbow was fully extended. Repetitions were executed without rest until the subject was not able to lower the weight slowly and in a controlled manner (i.e. ≥4 s) due to fatigue for 2 consecutive repetitions.

Signs of inflammation: Measures of signs of inflammation were made immediately before and 48 h after eccentric exercise. Assessments were performed 48 hours after exercise based upon evidence that shows peak soreness and inflammation occur in this time frame (Miles et al. 2008). Our assessment of inflammatory signs included measures of swelling, increased temperature and soreness, as these are hallmark characteristics of localized inflammation (Friden and Lieber 1992).

Swelling was assessed by measuring the circumference of the upper arm at the mid-brachium with a spring-loaded anthropometric tape. Swelling was also assessed by measuring arm volume, utilizing the water displacement method. This method is commonly used for monitoring lymphedema in breast cancer patients and has been shown to be sensitive to day-to-day fluctuations in arm volume that are associated with changes in edema (Lette, 2006). In brief, the volumeter is a vertical cylinder (100 cm tall, 15 cm in diameter) with a small spout at the top through which water can spill out. After filling the volumeter to the top with water, the subject slowly inserted their arm into the volumeter until a pre-marked area on the arm (near the insertion of the deltoid muscle) was at the water's surface. The water that spilled out of the volumeter was captured in a container and weighed. Water density was assumed to equal 1 $g \cdot mL^{-1}$; therefore, arm volume (in mL), was equal to the mass (in grams) of the displaced water. To ensure that the arm was inserted into the volumeter to the same level between baseline and 48-hr post exercise assessments, the subjects were advised to not wash off the reference mark on their arm between tests.

Temperature was measured using an infrared skin sensor (Dermatemp™ Infrared Temperature Scanner. Model # DT1000, Exergen Corp, Newton, Mass). A total of five temperatures were taken on the bicep mid brachii and the mean of all readings were used. Infrared thermometers are highly reliable and valid devices for measuring skin surface temperature (Burnham et al., 2006).

Soreness was measured using a visual analog scale on which the participants placed a tick mark on a 10 cm line to indicate the degree of soreness. The distance in centimeters from the left end of the scale to the tick mark was used to reflect soreness. Several studies have assessed the validity and reliably of the visual analog scale as a means for measuring subjective soreness (Gallagher et al., 2002). Muscle soreness was rated three ways: "Weighted" measures were made while the participants flexed and extended the elbow while holding a 1.1 kg weight; "Palpated" soreness was assessed with the participant relaxing their arm and while the technician palpated/massaged the bicep muscle ~2 cm inferior to the olecranon-to-acromion midpoint; "Fully extended" soreness ratings were made while the participants attempted to fully extend their elbow.

Omega-3 supplementation protocol: For the entire study subjects were placed on a restricted omega-3 fatty acid diet. The subjects were provided with a specific list

of omega-3 containing foods to avoid. This ensured that dietary omega-3 fatty acid intake was minimized. During the omega-3 trial, participants took 2,000 mg EPA and 1,000 mg DHA per day (Rx Omega-3 Factors, Natural Factors, Everett, Washington; 400 mg EPA and 200 mg DHA per softgel capsule). Previous research has used omega-3 fatty acid supplements in a ratio of EPA:DHA of 2:1 (Simopoulos, 2007). A supplement diary was given to each subject so they could record when they took the daily supplements. Additionally, pill counts were performed to assess compliance with the supplementation regimen. To maintain consistency with the amount of omega-3 fatty acids among subjects, the supplements were the only source of omega-3 fatty acids in the diet, as subjects continued to follow an omega-3 restricted diet.

Statistical analysis

Primary statistical analysis was performed on all subjects to assess the physiologic efficacy of the omega-3 supplementation. Change scores were calculated for each of the inflammatory markers by subtracting the final values (48 hr post exercise) from the baseline values (as measured immediately prior to eccentric exercise) for each trial. Paired t-tests were used to compare the change in inflammation from the control trial to the change in inflammation for the omega-3 trial. Statistical analysis was performed using SPSS software. A p-value of ≤ 0.05 was considered significant. Values are presented as mean ± SE unless indicated otherwise.

Results

Participants

Eight women (73%) and three men (27%) completed the study. Mean age (± SD) was in the middle to lower end of the targeted age range for the study (Table 1). BMI was 22.9 ± 2.0 $kg \cdot m^{-2}$, reflecting that most of the participants were lean to normal weight. As expected, men had greater 1RM than women. Strength in the dominant and non-dominant arms was similar for both men and women (Table 1). Pill counts indicated 100% compliance with the supplementation regimen.

Eccentric exercise performance

There was no difference (p = 1.00) in the weight used for eccentric exercise in the control trial (11.3 ± 4.2 kg) and the omega-3 trial (11.3 ± 4.6 kg). However, in the omega-3 trial, subjects completed more repetitions in set 1 (18 ± 3 vs. 21 ± 7 reps, p = 0.05) and set 2 (8 ± 3 vs. 10 ± 4 reps, p = 0.02), thereby resulting in greater total eccentric exercise volume (280 ± 73 vs. 321 ± 66 kg·repetitions, p= 0.01).

Post-exercise soreness

All three measures of muscle soreness showed very large increases in soreness between baseline and 48 h follow-up (Table 2), indicating that the exercise protocol induced significant arm soreness. Omega-3 supplementation attenuated the soreness based on the "weighted" and "fully extended" measures. Omega-3 supplementation also attenuated the "palpated" soreness, although this did not achieve statistical significance (p = 0.11).

Table 1. Subject characteristics. Values represent means (± standard deviation) or n (% of participants).

Sex, n (%)	**Men**	3 (27%)
	Women	8 (73%)
Height (m)	**Men**	1.80 (.10)
	Women	1.60 (.10)
Weight (kg)	**Men**	78.2 (3.0)
	Women	59.8 (8.5)
Age (yrs)	**Men**	37.0 (9.6)
	Women	34.1 (11.2)
BMI ($kg \cdot m^{-2}$)	**Men**	23.5 (.0)
	Women	22.1 (2.2)
1RM, dominant arm (kg)	**Men**	14.0 (1.7)
	Women	7.8 (2.3)
1RM, Non-dominant arm (kg)	**Men**	14.5 (2.4)
	Women	7.3 (2.3)

BMI: body mass index; 1RM; one repetition maximum.

Post-exercise swelling

Arm volume, did not change significantly between baseline and the 48 h follow up visit in either the control or omega-3 trial (Table 2). Although arm circumference increased significantly in the control trial but not in the omega-3 trial, the magnitude of increase in arm circumference was not different between trials (Table 2).

Post-exercise temperature

No statistical difference between baseline and 48 h follow-up measures of skin temperature were found. Furthermore, there was no difference found between the control and omega-3 trail with respect to changes in temperature in response to eccentric exercise.

Discussion

Results from the present study indicate that omega-3 fatty acid supplementation decreases muscle soreness after high-intensity eccentric exercise. This effect could be beneficial to athletes who undergo high-intensity strength training, which often produces delayed-onset muscle soreness. Furthermore, although we did not study lower intensity eccentric exercise, such as that which occurs during running, it is also possible that omega-3 fatty acid supplementation might attenuate the post exercise muscle soreness that occurs after activities such as marathon running. An omega-3 fatty acid dose of ≤ 3000 $mg \cdot day^{-1}$ (DHA+EPA) has been designated as safe for general consumption by the US Food and Drug Administration (Food and Drug Administration 2004). Until further research is done, one should abide by these recommendations if using fish oil for decreasing soreness and/or pain from exercise.

Pain, heat and swelling are signs associated with localized inflammatory process and can be measured non-invasively. We assessed the effect of omega-3 fatty acid supplementation on these hallmark characteristics of inflammation. Muscle soreness increased substantially after eccentric exercise, as evidenced by the soreness ratings. It is also noteworthy that most participants had such severe soreness that they struggled to achieve full elbow extension 48 h after exercise. Despite the severe soreness induced by eccentric exercise, arm volume, as a measure of swelling, and skin temperature did not change significantly in response to eccentric exercise, even in the

Table 2. Markers of inflammation in response to eccentric strength exercise. Data are means (±SE).

	Control Trial	Omega-3 Trial	Between Trials *P* value
Arm Volumetry, L			
Baseline	2.032 (.144)	1.997 (.141)	
48h Follow-up	2.060 (.145)	2.019 (.145)	
Change	.029 (.016)	.022 (.024)	.74
Within group P value	.11	.38	
Arm Circumference, cm			
Baseline	28.6 (1.0)	29.1 (1.0)	
48h Follow-up	29.2 (1.1)	29.4 (1.0)	
Change	.6 (.2)	.3 (.2)	.45
Within group P value	.01	.15	
Skin Temperature,°C			
Baseline	31.6 (.2)	31.9 (.2)	
48h Follow-up	31.3 (.2)	31.9 (.3)	
Change	-.3 (.2)	.0 (.3)	.34
Within group P value	.09	1.0	
Soreness, Weighted, cm on VAS*			
Baseline	.2 (.1)	.1 (.0)	
48h Follow-up	6.4 (.7)	5.1 (.7)	
Change	6.1 (.7)	5.0 (.7)	.02
Within group P value	<.0001	<.0001	
Soreness, Palpated, cm on VAS*			
Baseline	.2 (.1)	.4 (.3)	
48h Follow-up	6.2 (.7)	4.9 (.7)	
Change	6.0 (.6)	4.5 (.8)	.11
Within group P value	<.0001	<.0001	
Soreness, Fully Extended, cm on VAS*			
Baseline	.3 (.1)	.2 (.1)	
48h Follow-up	7.8 (.8)	6.6 (.8)	
Change	7.5 (.7)	6.4 (.8)	.004
Within group P value	<.0001	<.0001	

Within trial P values are from paired t-tests comparing baseline and 48h follow up values. Between trial P-values are from paired t-tests comparing change-scores in the control trial to change scores in the omega-3 trial. *Visual Analog Scale

control trial, indicating that these measures are not sensitive enough to change in response to eccentric biceps curls. Consequently, this precluded the possibility of determining if omega-3 fatty acid supplementation affects swelling and warmth as inflammatory characteristics.

One previous study found that a supplement containing the omega-3 fatty acid DHA attenuated the inflammatory response to eccentric exercise (Phillips et al. 2003). However, it is not clear if the beneficial effect was attributed to DHA, as the supplement also contained mixed tocopherols and flavonoids, which might have their own anti-inflammatory effects. Numerous other studies have demonstrated that omega-3 supplementation can act as a natural anti-inflammatory agent for people taking non steroidal anti-inflammatory drugs (NSAIDs) for medical conditions (Maroon and Bost, 2006a; Maroon and Bost, 2006b).

An unanticipated finding was that the participants performed more eccentric exercise after omega-3 supplementation. One explanation for this is that omega-3 supplementation increased muscle strength and/or decreased fatigue. Omega-3 fatty acids have anabolic properties in muscle tissue of healthy humans (Smith et al., 2011) and omega-3 rich fatty fish consumption is associated with grip strength in older adults (Robinson et al. 2008). Furthermore, EPA attenuates muscle wasting that is associated with cancer cachexia (Ryan et al., 2009), bacterial endotoxin exposure (Supinski et al., 2010), and arthritis (Castillero et al., 2009). However, these are not likely the main cause for the effects seen in the present study, especially in light of the short, weeklong supplementation period. An alternative explanation is that there was a "repeated bout effect" in which adaptations occurred between the first (control) and second (omega-3) trial (McHugh 2003) (because of long washout time for omega-3 (Cerbone et al., 1999) we designed the study so that the omega-3 trial always occurred last). We intended to preclude this possibility by using opposite arms for the control and omega-3 trials. However, while some research suggests that the repeated bout effect does not affect the contralateral limb (Connolly et al., 2002; Clarkson et al., 1987), a more recent study suggests that it does, at least partially (Howatson and van Someren, 2007). Nonetheless, it is intriguing that despite the fact that more eccentric work was performed in the omega-3 trail, soreness was significantly less.

The present study is limited in that the lack of a placebo group precludes the ability to rule out a potential psychological impact on subjective soreness ratings. However, anecdotally, most of the study participants did not have interest in the study outcome and those who did were skeptical about the potential soreness reducing effects of omega-3s. Thus, it seems unlikely that a placebo effect could explain our findings. Another limitation is that our sample size was small, thereby increasing the chances of a "false-positive" finding. Future research, using a larger sample and a randomized controlled design will be important for providing more definitive evidence.

Finally, it is important to recognize that the beneficial effects seen in the present study were achieved with a EPA/DHA ratio of 2:1 and a fairly large 3000 mg/d dose, requiring 1-2 softgel capsules to be taken at each meal. We cannot determine whether smaller, more economical, and more convenient dosing regimens would provide similar benefits. However, it is noteworthy that we saw beneficial effects after only 7-days of supplementation. This suggests that chronic supplementation is not necessary for protection against muscle soreness and that supplementation could be initiated in the ~7 days prior to activity that might cause soreness, such as a marathon or intensified period of strength training.

Muscle microtrauma, inflammation, and soreness are often caused by increases in physical activity such as vigorous training or competition in an elite athlete or physical therapy for rehabilitation from a hip fracture in an elderly patient. While NSAIDs are often used to treat post-exercise muscle soreness, omega-3 fatty acid supplementation could be a safer and healthier alternative (Maroon and Bost, 2006b). In addition to attenuating muscle soreness, omega-3 fatty acids may protect against cardiovascular disease (Lavie et al., 2009) and cardiac arrhythmias (Richardson et al., 2011), slow the age-related decline in cognitive function (Fotuhi et al., 2009), and protect against some forms of cancer (Rose and Connolly, 1999). In contrast, there appear to be very few adverse effects from omega-3 fatty acid supplementation, with the main concern being increased bleeding time (and theoretically an increased risk of hemorrhagic stroke) at intakes >3000 $mg \cdot d^{-1}$ (Food and Drug Administration 2004), an effect which might have important ramifications for individuals on anticoagulation therapies. However, this effect has not been substantiated in clinical trials (Bays, 2007). Other concerns about omega-3 fatty acid supplementation are related the possible presence of pollutants (from fish sources) (Bourdon et al., 2010) and the proneness to oxidation. However, these issues are not directly related to omega-3 fatty acid consumption, per se, and can be managed with proper manufacturing methods (i.e. fish source monitoring or use of algal sources), and storage techniques (for example, using vitamin E as an antioxidant preservative).

Conclusion

In conclusion, these preliminary findings suggest that 1 week of 3000 $mg \cdot d^{-1}$ of DHA/EPA omega-3 supplementation decreases the severe localized soreness, as a sign of inflammation, that results from eccentric strength exercise. Based on these findings, omega-3 supplementation could provide benefits by minimizing post-exercise soreness and thereby facilitate exercise training in individuals ranging from athletes undergoing heavy conditioning to sedentary subjects or patients who are starting exercise programs or medical treatments such as physical therapy or cardiac rehabilitation.

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References

Bays, H.E. (2007) Safety considerations with omega-3 fatty acid therapy. *American Journal of Cardiology* **99,** 35C-43C.

Berger, R.A. (1961) Determination of the resistance load for 1RM and 10RM. *Journal of the Association for Physical and Mental Rehabilitation* **15,** 108-110.

Bittiner, S.B., Tucker, W.F., Cartwright, I. and Bleehen, S.S. (1988) A double-blind, randomised, placebo-controlled trial of fish oil in psoriasis. *Lancet* **1,** 378-380.

Bourdon, J.A., Bazinet, T.M., Arnason, T.T., Kimpe, L.E., Blais, J.M. and White, P.A. (2010) Polychlorinated biphenyls (PCBs) contamination and aryl hydrocarbon receptor (AhR) agonist activity of Omega-3 polyunsaturated fatty acid supplements: implications for daily intake of dioxins and PCBs. *Food and Chemical Toxicology*. **48,** 3093-3097.

Burnham, R.S., McKinley, R.S. and Vincent, D.D. (2006) Three types of skin-surface thermometers: a comparison of reliability, validity, and responsiveness. *American Journal of Physical Medicine and Rehabilitation* **85,** 553-558.

Calder, P.C. (2006) n-3 polyunsaturated fatty acids, inflammation, and inflammatory diseases. *American Journal of Clinical Nutrition* **83,** 1505S-1519S.

Castillero, E., Martin, A.I., Lopez-Menduina, M., Villanua, M.A. and Lopez-Calderon, A. (2009) Eicosapentaenoic acid attenuates arthritis-induced muscle wasting acting on atrogin-1 and on myogenic regulatory factors. *American Journal of Physiology. Regulatory, Integrative and Comparative Physiology* **297,** R1322-R1331.

Cerbone, A.M., Cirillo, F., Coppola, A., Rise, P., Stragliotto, E., Galli, C., Giordano, M., Tremoli, E. and Di Minno, G. (1999) Persistent impairment of platelet aggregation following cessation of a short-course dietary supplementation of moderate amounts of N-3 fatty acid ethyl esters. *Thrombosis and Haemostasis* **82,** 128-133.

Clarkson, P.M., Byrnes, W.C., Gillisson, E. and Harper, E. (1987) Adaptation to exercise-induced muscle damage. *Clinical Science (London)* **73,** 383-386.

Cleland, L.G., James, M.J. and Proudman, S.M. (2003) The role of fish oils in the treatment of rheumatoid arthritis. *Drugs* **63,** 845-853.

Connolly, D.A.J., Reed, R.V. and McHugh, M.P. (2002) The repeated bout effect: does evidence for a crossover effect exist? *Journal of Sports Science and Medicine* **1,** 80-86.

Curtis, C.L., Rees, S.G., Little, C.B., Flannery, C.R., Hughes, C.E., Wilson, C., Dent, C.M., Otterness, I.G., Harwood, J.L. and Caterson, B. (2002) Pathologic indicators of degradation and inflammation in human osteoarthritic cartilage are abrogated by exposure to n-3 fatty acids. *Arthritis and Rheumatism* **46,** 1544-1553.

Food and Drug Administration. (2004) 21 CFR Part 184 [Docket No. 1999P-5332]. *Federal Register* **69,** 2313-2317.

Fotuhi, M., Mohassel, P. and Yaffe, K. (2009) Fish consumption, long-chain omega-3 fatty acids and risk of cognitive decline or Alzheimer disease: a complex association. *Nature Clinical Practice Neurology* **5,** 140-152.

Friden, J. and Lieber, R. -L. (1992) Structural and mechanical basis of exercise-induced muscle injury. *Medicine and Science in Sports and Exercise* **24,** 521-530.

Gallagher, E.J., Bijur, P.E., Latimer, C. and Silver, W. (2002) Reliability and validity of a visual analog scale for acute abdominal pain in the ED. *American Journal of Emergency Medicine* **20,** 287-290.

Hirose, L., Nosaka, K., Newton, M., Laveder, A., Kano, M., Peake, J. and Suzuki, K. (2004) Changes in inflammatory mediators following eccentric exercise of the elbow flexors. *Exercise Immunology Review* **10,** 75-90.

Howatson, G. and van Someren, K.A. (2007) Evidence of a contralateral repeated bout effect after maximal eccentric contractions. *European Journal of Applied Physiology* **101,** 207-214.

Kim, Y.I. (1996) Can fish oil maintain Crohn's disease in remission? *Nutrition Reviews* **54,** 248-252.

Kojima, T., Terano, T., Tanabe, E., Okamoto, S., Tamura, Y. and Yoshida, S. (1989) Effect of highly purified eicosapentaenoic acid on psoriasis. *Journal of the American Academy Of Dermatology* **21,** 150-151.

Kremer, J.M., Lawrence, D.A., Jubiz, W., DiGiacomo, R., Rynes, R., Bartholomew, L.E. and Sherman, M. (1990) Dietary fish oil and olive oil supplementation in patients with rheumatoid arthritis. Clinical and immunologic effects. *Arthritis and Rheumatism* **33,** 810-820.

Lau, C.S., Morley, K.D. and Belch, J.J. (1993) Effects of fish oil sup-

plementation on non-steroidal anti-inflammatory drug requirement in patients with mild rheumatoid arthritis--a double-blind placebo controlled study. *British Journal of Rheumatology* **32,** 982-989.

Lavie, C.J., Milani, R.V., Mehra, M.R. and Ventura, H.O. (2009) Omega-3 polyunsaturated fatty acids and cardiovascular diseases. *Journal of the American College of Cardiology* **54,** 585-594.

Lette, J. (2006) A simple and innovative device to measure arm volume at home for patients with lymphedema after breast cancer. *Journal of Clinical Oncology* **24,** 5434-5440.

Maroon, J. and Bost, J. (2006a) *Fish oil: The natural anti-inflammatory.* Basic Health Publications, Inc. Laguna Beach. CA.

Maroon, J.C. and Bost, J.W. (2006b) Omega-3 fatty acids (fish oil) as an anti-inflammatory: an alternative to nonsteroidal anti-inflammatory drugs for discogenic pain. *Surgical Neurology* **65,** 326-331.

McHugh, M.P. (2003) Recent advances in the understanding of the repeated bout effect: the protective effect against muscle damage from a single bout of eccentric exercise. *Scandinavian Journal of Medicine and Science in Sports* **13,** 88-97.

Miles, M.P., Andring, J.M., Pearson, S.D., Gordon, L.K., Kasper, C., Depner, C.M. and Kidd, J.R. (2008) Diurnal variation, response to eccentric exercise, and association of inflammatory mediators with muscle damage variables. *Journal of Applied Physiology* **104,** 451-458.

Nosaka, K. and Clarkson, P.M. (1996) Changes in indicators of inflammation after eccentric exercise of the elbow flexors. *Medicine and Science in Sports and Exercise* **28,** 953-961.

Phillips, T., Childs, A.C., Dreon, D.M., Phinney, S. andd Leeuwenburgh, C. (2003) A dietary supplement attenuates IL-6 and CRP after eccentric exercise in untrained males. *Medicine and Science in Sports and Exercise* **35,** 2032-2037.

Richardson, E.S., Iaizzo, P.A. and Xiao, Y.F. (2011) Electrophysiological mechanisms of the anti-arrhythmic effects of omega-3 fatty acids. *Journal of Cardiovascular Translational Research* **4,** 42-52.

Robinson, S.M., Jameson, K.A., Batelaan, S.F., Martin, H.J., Syddall, H.E., Dennison, E.M., Cooper, C. and Sayer, A.A. (2008) Diet and its relationship with grip strength in community-dwelling older men and women: the Hertfordshire cohort study. *Journal of the American Geriatrics Society* **56,** 84-90.

Rose, D.P. and Connolly, J.M. (1999) Omega-3 fatty acids as cancer chemopreventive agents. *Pharmacology and Therapeutics* **83,** 217-244.

Ross, E. (1993) The role of marine fish oils in the treatment of ulcerative colitis. *Nutrition Reviews* **51,** 47-49.

Ryan, A.M., Reynolds, J.V., Healy, L., Byrne, M., Moore, J., Brannelly, N., McHugh, A., McCormack, D. and Flood, P. (2009) Enteral nutrition enriched with eicosapentaenoic acid (EPA) preserves lean body mass following esophageal cancer surgery: results of a double-blinded randomized controlled trial. *Annals of Surgery* **249,** 355-363.

Salomon, P., Kornbluth, A.A. and Janowitz, H.D. (1990) Treatment of ulcerative colitis with fish oil n--3-omega-fatty acid: an open trial. *Journal of Clinical Gastroenterology* **12,** 157-161.

Simopoulos, A.P. (2007) Omega-3 fatty acids and athletics. *Current Sports Medicine Reports* **6,** 230-236.

Smith, G.I., Atherton, P., Reeds, D.N., Mohammed, B.S., Rankin, D., Rennie, M.J. and Mittendorfer, B. (2011) Omega 3 polyunsaturated fatty acids augment the muscle protein anabolic response to hyperaminoacidemia-hyperinsulinemia in healthy young and middle aged men and women. *Clinical Science (London)* **121,** 267-278

Stenson, W.F., Cort, D., Rodgers, J., Burakoff, R., DeSchryver-Kecskemeti, K., Gramlich, T.L. and Beeken, W. (1992) Dietary supplementation with fish oil in ulcerative colitis. *Annals of Internal Medicine* **116,** 609-614.

Supinski, G.S., Vanags, J. and Callahan, L.A. (2010) Eicosapentaenoic acid preserves diaphragm force generation following endotoxin administration. *Critical Care* **14,** R35.

Trappe, T.A., Fluckey, J.D., White, F., Lambert, C.P. and Evans, W.J. (2001) Skeletal muscle PGF(2)(alpha) and PGE(2) in response to eccentric resistance exercise: influence of ibuprofen acetaminophen. *Journal of Clinical Endocrinology and Metabolism* **86,** 5067-5070.

Volker, D., Fitzgerald, P., Major, G. and Garg, M. (2000) Efficacy of fish oil concentrate in the treatment of rheumatoid arthritis. *Journal of Rheumatology* **27,** 2343-2346.

Weber, P.C., Fischer, D., vonSchacky, C., Lorenz, R. and Strasser, T. (1986) Dietary Omega Polyunsaturated fatty acids and eicosanoid formation in man. In: *Health effects of polyunsaturated fatty acids in seafoods.* Academic Press, Orlando. 49-60.

Key points

- Dietary supplementation with omega-3 fatty acids has been shown to reduce inflammation in numerous inflammatory diseases such as rheumatoid arthritis, inflammatory bowel disease, and Chrohn's disease.
- Although strenuous exercise is known to cause acute increases in inflammation, it is not clear if omega-3 fatty acid supplementation attenuates this adverse response to exercise.
- Our research demonstrates that 3000 $mg \cdot d^{-1}$ omega-3 fatty acid supplementation minimizes the severe, delayed-onset muscle soreness that results from strenuous eccentric strength exercise.
- This information, along with a plethora of information showing that omega-3 fatty acid supplementation has other health benefits, demonstrates that a readily available over the counter nutritional supplement (i.e. omega-3 fatty acids) reduces delayed-onset soreness caused by strenuous strength exercise.
- This information has obvious relevance to athletic populations but also to other groups such as physical therapy patients and newly admitted cardiac rehabilitation patients, as muscle soreness, if left unchecked, can slow the progress in adapting to a new exercise program.
- Furthermore, as inflammation is known to be involved in the pathogenesis if numerous diseases, including heart disease, cancer, and diabetes, it is likely prudent for individuals to use inflammation-attenuating interventions, such as omega-3 supplementation, to keep inflammatory responses to physical activity at a minimum.

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