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Fish oil supplementation inhibits NNK-induced lung carcinogenesis in the A/J mouse

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Abstract

High intake of fish oil with a low omega-6 (n-6)/omega-3 (n-3) polyunsaturated fatty acid (PUFA) ratio has been suggested to protect against many chronic diseases. However, the effect of different ratios of dietary n-6 and n-3 PUFA on lung tumorigenesis has not been investigated. In this study, we examined the effect of a 4 month dietary supplementation with corn oil (with a high n-6/n-3 ratio) and fish oil (with a low n-6/n-3 ratio) as compared with soybean oil (isocaloric control with the same n-6/n-3 ratio as the base diet) on tumor incidence and tumor prevalence in the A/J mouse model of 4-(methylnitrosamino)-1-(3-pyridyl)-1-butanone (NNK)-induced lung carcinogenesis. We found that dietary supplementation had no effect on overall lung tumor incidence but fish oil supplementation was able to decrease lung tumor prevalence by 78% and 80%, compared to groups receiving soybean oil and corn oil supplementation, respectively. The inhibitory effect of fish oil on lung tumor prevalence was associated with increased expressions of cell cycle inhibitor p21Cip1 and lipoxygenase isoforms 15-LOX in the lungs. These data suggest that fish oil with a low ratio of n-6/n-3 PUFA could be beneficial in the prevention of lung carcinogenesis.

Keywords

fish oil; omega-3 polyunsaturated fatty acids; lung cancer; lipoxygenase enzymes

Introduction

Lung cancer is the most common cancer and the leading cause of cancer death both globally and in the United States. Despite great efforts to improve smoking cessation and the treatment of patients with lung cancer, the survival rate for people diagnosed with this disease has not significantly improved over the past 30 years, which underscores dietary intervention as one of the main strategies for preventing lung cancer. Although its preventive role against cancer has yet to be conclusively established (1), high intake of fish oil/omega-3 polyunsaturated fatty acids (n-3 PUFA) has been suggested to protect against many chronic diseases including cancers (2–5). A significant inverse correlation between fish consumption and lung cancer

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mortality was found in men in countries with high levels of cigarette smoking or animal fat consumption, such as Iceland and Japan (6). In case-control studies, a retrospective case-control study among Hong Kong Chinese women who never smoked tobacco found that those in the lowest tertile of consumption of fresh fish had a statistically significant adjusted relative risk of 2.8 for developing lung cancer (7); and a comparison of 71 consecutive new male cases of lung cancer and 71 male hospital control patients showed a significantly lower intake of fish in lung cancer patients (8). In prospective studies, a study in Norway involving 51,452 subjects and 154 lung cancer cases noted a significant protective effect of cod liver oil (rich in n-3 PUFA) against lung cancer (9); and a Japanese prospective study showed that frequent consumption of fresh fish or shellfish was associated with lower lung cancer risk (10). However, other studies showed fish intake was not associated with either lung cancer risk (11) or lung cancer death (12). One explanation for these inconsistent results may be confounding by varying intakes of other fatty acids, such as omega-6 polyunsaturated fatty acids (n-6 PUFA) from vegetable oil. Studies have indicated that in contrast to the cancer preventive effect of n-3 PUFA, n-6 PUFA such as linoleic acid (LA) is associated with higher risk of cancer (13). This leads to the hypothesis that the ratio of dietary n-6 to n-3 PUFA may be the most important factor in determining cancer risk relative to fatty acid intake. This notion is supported by the observation that the growth of implanted melanoma cells and lung cancer cells was dramatically inhibited in mice whose n-6/n-3 fatty acid were genetically decreased (14,15) whereas the lung tumor volume was increased in NNK-treated rats fed with dietary corn oil from 5% to 23.5% (16). However, the effect of different ratios of dietary n-6 and n-3 PUFA on carcinogen-induced lung tumorigenesis has not been investigated.

One explanation for the anti-carcinogenic activity of n-3 PUFA is their ability to modulate arachidonic acid (AA) metabolism (17). AA is a predominant fatty acid in cell membranes. It is a metabolite of LA, a major n-6 PUFA in vegetable oils such as corn oil and soybean oil, generated by desaturation and elongation. α-Linolenic acid (ALA), a major n-3 PUFA in vegetable oil, shares the same metabolic pathway and generates eicosapentaenoic acid (EPA) and docosahexaenoic acid (DHA), which are also available from fish oil. Therefore, dietary LA and ALA may compete with each other for metabolizing enzymes. Furthermore, AA, EPA and DHA all serve as substrates for cyclooxygenase (COX) and lipooxygenase (LOX) enzymes to generate eicosanoids that can affect diverse biological processes (17,18). COX enzyme products give rise to prostaglandins and thromboxanes, while LOX enzymes produce leukotrienes, hydroxyfatty acids, and lipoxins. In general, n-6 PUFA-derived eicosanoids seem to have pro-inflammatory effects and have been linked to carcinogenesis, whereas n-3 PUFA-derived eicosanoids have been associated with anti-inflammatory effects (19–21). Therefore, n-3 PUFA including ALA, EPA, and DHA can compete with n-6 PUFA such as LA and AA for enzyme availability, resulting in an altered response to cancer cells and modulation of inflammation, cellular proliferation, apoptosis, metastasis, and angiogenesis (17,19). In addition, n-3 PUFA may also directly affect the expression of fatty acid metabolizing enzymes. For example, EPA and DHA were shown to inhibit cytokine-induced COX-2 gene transcription *in vitro* and *in vivo* (22,23). There have been no reports of the effect of n-3 PUFA supplementation on the expression of LOX and COX2 enzymes, so this remains an area of research interest.

Previously, it has been shown that in Lewis lung carcinoma-bearing C57BL/6 mice, a diet containing 5% fish oil resulted in significantly slower growth of primary tumors, lower mortality rate, and lower metastatic spread, compared with tumor-bearing mice on a diet containing 5% soybean oil (24). However, no studies have been conducted to examine whether high intake of omega-3 PUFA or a diet containing low ratio of n-6 to n-3 PUFA can affect lung tumorigenesis. Using the A/J mouse model of 4-(methylnitrosamino)-1-(3-pyridyl)-1-butanone (NNK)-induced lung carcinogenesis (25), a widely used animal model for lung cancer, we have shown the potential chemopreventive effect of dietary supplementation with

9-cis-retinoic acid (26), 1α,25-dihydroxyvitamin D_3 (27) and lycopenoic acid (28) against lung carcinogenesis. The goal of this research was to determine whether oils with differing content of n-6 and n-3 PUFA could exert measurable effects on tumor incidence and tumor prevalence in the A/J mouse model of lung cancer. Furthermore, we determined whether dietary supplementation with different ratios of n-3/n-6 PUFA could alter gene expression of COX-2, lipoxygenase enzymes (5-LOX, 8-LOX, 12-LOX, or 15-LOX), and several cell cycle regulators (p21, p27, Cyclin D, or Cyclin E) in the mouse lung.

Materials and Methods

Polyunsaturated Oils

Menhaden fish oil (donated by Omega Protein, Inc., Reedville, VA) contains approximately 30.5% total n-3 PUFA (including 12.9% of EPA, 8.17% of DHA, and 2.03% of ALA) and 5.1% total n-6 PUFA (including 1.73% of LA and 0.22% of AA). Corn oil (Crisco® pure corn oil) and soybean oil (Mazola® 100% vegetable oil) were purchased commercially. Based on USDA national nutrition database values, corn oil contains 53.5% of n-6 PUFA (predominantly LA) and 1.2% of n-3 PUFA as ALA, while soybean oil contains 51.0% of n-6 PUFA mainly as LA and 6.8% of n-6 PUFA as ALA. The n-6/n-3 PUFA ratios for fish oil, soybean oil, and corn oil used are estimated as 0.2, 7.5, and 46.1, respectively.

Animal Model and Experimental Design

Male A/J mice (6 weeks old) obtained from Jackson Labs (Bar Harbor, ME) were randomly assigned to one of five experimental groups (n = 14 animals per group). Each group was fed AIN-93M semi-purified diet (Dyets, Bethlehem, PA), for two weeks, and then switched over to experimental diets as follows:

Group I (Sham + Control): Control diet (AIN-93M) plus i.p. injection of 0.20 ml normal saline/kg body weight

Group II (NNK + Control): Control diet plus i.p. injection of 100 mg NNK/kg body weight

Group III (NNK + Fish oil): Control diet supplemented with menhaden fish oil (10%) plus i.p. injection of 100 mg NNK/kg body weight

Group IV (NNK + Corn oil): Control diet supplemented with corn oil (10%) plus i.p. injection of 100 mg NNK/kg body weight

Group V (NNK + Soybean oil): Control diet supplemented with soybean oil (10%) plus i.p. injection of 100 mg NNK/kg body weight

Previous work has shown that a single intraperitoneal injection of 2 mg or 100 mg/kg body weight of 4-(methylnitrosamino)-1-(3-pyridyl)-1-butanone (NNK) was sufficient to induce tumors in 100% of A/J mice at a level of 10–12 adenomas per mouse at 16 weeks post-injection (25,26,29). In this study, treatment of A/J mice with oil diets began three weeks prior to intraperitoneal injection of 100 mg NNK/kg body weight (Toronto Research Chemicals, Inc., Ontario, Canada).

The AIN-93M base diet contains 4% soybean oil (wt/wt), and oil-supplemented groups received 10% (wt/wt) fish oil, corn oil, or soybean oil in addition to the oil in the base diet. Thus, oil-supplemented groups were all maintained on 14% fat diets, but each diet had a different n-6/n-3 fatty acid ratio. The corn oil-supplemented diet had a high n-6/n-3 fatty acid ratio, the fish oil-supplemented diet had a low n-6/n-3 fatty acid ratio, and the soybean oil-supplemented diet served as an isocaloric control, with the same n-6/n-3 fatty acid ratio as the base diet, but the higher caloric density of the experimental diets. Oils were mixed directly into powdered AIN-93M diet. Oil supplemented diets were prepared in 2 kg batches once a month

and stored in 500 g airtight bags under nitrogen blanket at −20°C to delay oxidative decomposition of the oils. Once opened, diets were used for one week, giving animals fresh portions daily and storing the remainder at 4°C under nitrogen blanket. Because the fish oil was supplemented with vitamin E by the manufacturer to prevent oxidative degradation, vitamin E (27 mg/kg diet, all-*rac*-α-tocopherol acetate, Roche Vitamins, Inc., Parsippany, NJ) was added to the corn and soybean oils to maintain similar levels among the three oil-supplemented diets to control for potential antioxidant effects on carcinogenesis.

Mice were maintained on study diets for 17 weeks post-injection, fed ad libitum,, observed daily and weighed weekly. Mice were fasted for at least 12 hours prior to terminal exsanguination under deep anesthesia (5% isoflurane, Baxter Healthcare Corp., Deerfield, IL) and blood was collected and stored as plasma. The right lungs were perfused with buffered Formalde-Fresh solution (Fisher Chemicals, Fairlawn, NJ) and maintained in Formalde-Fresh until sectioning and slide preparation. The left lungs were snap frozen in liquid nitrogen and stored at −80°C for subsequent analysis.

Quantitation of Lung Lesions

Lung lesions were quantified by determining the incidence and prevalence of pulmonary pleural surface tumors, counting both the right and left lungs of each mouse. Tumor incidence was defined as the number of lung sets (right and left lungs) in each group containing one or more tumors divided by the total number of lung sets examined. Tumor prevalence (mean number of tumors per mouse) was defined as the total number of pulmonary tumors in each group divided by the total number of lung sets examined. Lung tumors were visually counted by two researchers blinded to the treatment group, and lung sections were microscopically examined to confirm presence of bronchioalveolar adenoma.

Real-Time PCR Analysis

Total RNA was isolated from lung tissue using RNeasy Mini Kits (Qiagen, Inc., Valencia, CA) according to the manufacturer's protocol. cDNA was prepared from the RNA samples using M-MLV reverse transcriptase (Invitrogen, Carlsbad, CA) and an automated thermal cycler (MJ Research PTC-200, Bio-Rad Laboratories, Hercules, CA), and quantified using a fluorescence-based real-time detection method (ABI PRISM 7000 Sequence Detection System, Perkin-Elmer Applied Biosystems, Foster City, CA) using SYBR Green reagents (Applied Biosystems, Foster City, CA). The PCR reaction was carried out in 20 μL of reaction mixture containing 10 μL of Power SYBR Green PCR Mastermix, 1 μL of 10 μM primer mix (including forward and reverse primers for target genes or an internal reference gene, β-actin), and 9 μL (25 ng) of cDNA diluted in RNase-free water. Cycling conditions were 50°C for 2 min and 95°C for 2 minutes, followed by 40 cycles at 95°C for 15 seconds and 60°C for 30 seconds. Melting curves were run following the cycling program to confirm the specificity of the reaction for the amplicon. Sequences for primers are as follows (Sigma-Genosys, The Woodlands, TX):

Gene	Accession number	Primer sequence
p21Cip1	NM_001111099	forward primer ATTCAGAGCCACAGGCACCAT
		reverse primer TCAAAGTTCCACCGTTCTCGG
COX-2	NM_011198	forward primer GCTGCCCGACACCTTCAA
		reverse primer TCTTCCCCCAGCAACCC
5-LOX	NM_009662	forward primer CTGAGGTGTTTGGTATCGCCAT
		reverse primer GGCATTGGCCTTGTCAAAAAG
8-LOX	NM_009661	forward primer AGTTCAGGCCAGTTCGACTCTT
		reverse primer CAGCCAGAGAGCAATGATGTG
12-LOX	NM_007440	forward primer CGGCCATGTTCAGTTGCTTACT

		reverse primer ATCCCCTTCACATACCTGGCA
15-LOX	NM_009660	forward primer AGCTCATTGTGTCCCCCTGAT
		reverse primer ACATTCCCACCACGTACCGAT
β-actin	NM_007393	forward primer TAGACTTCGAGCAGGAGATGGC
		reverse primer CCACAGGATTCCATACCCAAGA

The primers sequences for p27, cyclin D and E are as described (28). Relative standard curves and relative efficiency plots were constructed and verified over the working range of mRNA levels to confirm that amplification efficiencies of the genes were approximately equal to the endogenous control gene, β-actin. Quantification of gene expression was calculated relative to average values for the Sham control group using the comparative Ct method. For each sample and each gene, PCR reactions were carried out in duplicate.

Statistical Analyses

A student t-test was used to compare means between sham + control and NNK + control groups (with same diet but different NNK treatment) and between NNK + control and NNK + soybean oil groups (with same NNK treatment and same ratio of n-6/n-3 but receiving different amount of oil in the diet). A one-way ANOVA analysis with Fisher's least significant difference (LSD) method was used to compare means across oil-supplemented groups (receiving same amount of oils but with n-6/n-3 ratio). A difference was considered significant at $p < 0.05$.

Results

Effects of Fish Oil and Corn Oil on Body Weight and Lung Tumors

There were no significant differences in mean body weight between groups at baseline or at the end of dietary supplementation period (Table 1). This suggests that animals were able to adjust dietary intake relative to the caloric density of the diet. There were no tumors present in any of the lungs examined from the sham plus control group at 16 weeks. While spontaneous lung tumors can form in A/J mice, the incidence of spontaneous tumors in mice 25 weeks old is very low so a lack of tumors in this group was not surprising (30). Compared to this group, the groups receiving NNK alone or NNK plus different oils had significantly higher tumor incidence and tumor prevalence ($p < 0.001$ for both, Table 2). No difference in tumor incidence and prevalence was found between mice receiving NNK plus soybean oil (containing 14% soybean oil) and mice receiving NNK treatment and fed a base diet (containing 4% soybean oil) diet (Table 2). Compared to the soybean oil group, neither fish oil nor corn oil supplementation affected tumor incidence (100% in all three groups); however, animals in the fish oil supplemented group had significantly lower tumor prevalence, (78% lower, $p < 0.001$) (Table 2). The size of the lung tumors among the groups were fairly consistent (between 0.8–1.2 mm) and only a few slightly larger tumors (~2 mm) were observed in the current study and in our previous studies (26–28).

Effects of Fish Oil and Corn Oil on Lung Expression of LOX and COX2 enzymes

The effect of dietary n-6 and n-3 PUFA on the expression of COX and LOX enzymes were compared among groups of mice supplemented with corn, soybean, and fish oil. There were no significant differences in COX-2, 5-LOX, or 8-LOX mRNA levels among the three groups (Table 3). Fish oil supplementation significantly increased mRNA levels of 12-LOX and 15-LOX by 58% and 5 fold, respectively, as compared with mice fed with soybean oil (Table 3). There was no significant difference in 12-LOX and 15-LOX mRNA between corn oil and soybean oil groups (Table 3). Neither NNK treatment nor increased dietary fat intake significantly affects expression of COX-2 and LOX enzymes in mouse lung tissues (Table 3).

Effect of Fish Oil and Corn Oil on Lung Expression of cell cycle regulators

Higher mRNA levels of p21, a cell cycle inhibitor gene, were observed in the lung tissues of mice fed fish oil, as compared with mice fed soybean oil and corn oil (Table 3). Neither NNK treatment nor increased dietary fat intake significantly affects p21Cip1 expression in mouse lung tissues (Table 3). No significant changes in the expression levels of other genes regulating cell growth or survival, such as p27Kip1, cyclin D, and cyclin E were detected in the lung tissues of mice treated with NNK or supplemented with different oil (data not shown).

Discussion

In the present study, we determined the effect of dietary supplementation with 10% fish oil (with higher levels of EPA and DHA, low n-6/n-3 ratio) and 10% corn oil (with higher levels of LA, high n-6/n-3 ratio), as compared with supplementation with 10% soybean oil, a similar source of caloric density that maintains the n-3/n-6 PUFA ratio of the base diet that contains 4% soybean oil, on tumor incidence and tumor prevalence in the A/J mouse model of lung cancer. Our results showed that supplementation with 10% fish oil (wt/wt) resulted in significantly lower lung tumor prevalence in A/J mice four months after carcinogen injection. While previous studies have shown that supplementation with fish oil (31) or EPA/DHA (32) significantly inhibited the growth of xenografted tumors in mouse models, this is the first study to show that fish oil decreases lung tumor development *in vivo* in a carcinogen-induced lung cancer model, suggesting a preventive effect of n-3 PUFA against lung tumorigenesis. This study also reinforces the ratio of dietary n-6 to n-3 PUFA as the important factor in dietary chemoprevention.

It has been suggested that the beneficial effect of n-3 PUFA is attributed to long chain fatty acids, predominant EPA and DHA (17). When compared with soybean oil and corn oil, fish oil contains much higher levels of EPA and DHA, while the major n-3 PUFA in corn oil and soybean oil is ALA, which is incorporated to phospholipids and then converted to EPA and DHA after absorption. However, the estimated efficiency for the conversion of ALA into EPA in humans only ranges between 0.2% and 8% (33). Therefore, supplementation with fish oil will result in much higher levels of EPA and DHA in mouse tissues, as compare with corn oil and soybean oil supplementation, which may account for the significant lower tumor numbers in lung tissue of oil-supplemented mice.

In the current study, while we were able to show that supplementation with fish oil provides chemopreventive effects against lung carcinogenesis, we did not observe any promoting effects associated with supplementation with corn oil. This is in contrast to earlier studies that have shown that diets enriched in corn oil or LA increased tumor growth and development in rodent models of breast (34,35), colon (36,37), and prostate cancer (38,39). With respect to lung cancer, a diet enriched in corn oil (20% vs. 5%) was shown to increase lung tumor volume and reduce tumor latency in F344 rats treated with NNK (16). One explanation for our conflicting results lies in the model we used in the study. With NNK-injected control animals developing an average of 15.5 lung tumors per mouse, it is possible that promoting factors may not be able to induce additional tumors beyond this level. Therefore, we can not exclude the possibility that the ratio of n-6/n-3 PUFA in corn oil could influence the process of lung carcinogenesis. Further study either using either a lower dosage of carcinogen or examining earlier time points in the process of tumor initiation and promotion may address the issue.,

Both omega-3 and omega-6 fatty acids are substrates for COX and LOX enzymes to generate biologically active eicosanoids. Several distinctive isoforms of LOX enzymes have been identified in mice and in humans, which stereo-specifically insert oxygen into polyunsaturated fatty acids and generate 5-, 8-, 12-, or 15-hydroperoxyeicosatetraenic acids (HPETE) and leukotrienes (40). In the present study we showed that fish oil supplementation significantly

increased mRNA levels of 15-LOX and, to a much lesser extent, 12-LOX; whereas mRNA levels of COX-2, 5-LOX, and 8-LOX were not affected by oil supplementation. The increased expression of 15-LOX was associated with decreased NNK-induced lung tumor numbers. Recently, 15-LOX-1 and 15-LOX-2 (corresponding to 8-LOX in mouse) have been suggested to suppress tumorigenesis (40), while 5-LOX and 12-LOX are generally considered pro-carcinogenic. For example, 15-LOX is preferentially expressed in normal tissues and benign lesions, and less in malignant tissues as well as in cancer cell lines (41–43). The overexpression of 15-LOX has been shown to inhibit cell growth and induce apoptosis in colon and pancreatic cancer cells (43,44). Furthermore, it has been shown that 15-LOX mediates non-steroidal anti-inflammatory drug-induced apoptosis in colon cancer cells (45) and gastric cancer cells (46). Thus, the higher expression of 15-LOX in fish oil-fed mice might have contributed to the lower prevalence of lung tumors in this study. The expression of 12-LOX has been shown to increase in various epithelial cancers including prostate, breast, and pancreatic cancer (47–49) and the inhibition of 12-LOX was shown to induce cancer cell apoptosis (50) and inhibit tumor promotion (51). Since the fish oil-induced increase in 12-LOX was much less than that in 15-LOX, the significance of 12-LOX observed effects in this study is questionable.

While having significantly lower tumor multiplicity in the group receiving fish oil supplementation, we did not detect any significant changes in COX-2 message or protein levels (52–54). One explanation for this could be differences in the method of NNK administration. Continuous administration of NNK in the drinking water may increase COX-2 expression (52), while a single dose of NNK may result in acute changes in gene expression that do not persist over the duration of the study (26). Further, the lack of significant changes in the expression of COX-2 gene may be due to the COX-2 activity without necessarily altering protein levels. An effect on decreased enzyme activity and reduced prostaglandin E2 production could not be confirmed in our *in vivo* study due to analytical limitations on frozen tissue samples.

In the present study, the significantly lower tumor multiplicity in the group receiving fish oil supplementation was associated with increased p21 mRNA expression in lung tissues. p21, the product of the *CIP1/WAF1/SDI1* gene, was shown to inhibit G1 cyclin/cyclin-dependent kinase complexes, and acts to constrainthe cell cycle and facilitate tumor growth arrest. It has been shown that expression of p21 is a significant factor in predicting a favorable prognosis in patients with non-small cell lung cancer (55). Our result is in agreement with recent report that the fish oil supplementation enhanced p21 expression which was associated with a decrease in aberrant crypt formation in the colon of azoxymethane-treated rats (56). While p21 is a potent regulator of cyclins E and cyclin D-dependent kinases, we did not detect significant changes in the expression levels of other genes regulating cell growth or survival, such as cyclin D, and cyclin E and p27Kip1. The lack of significant changes in the expression of these genes may be due to the method in which RNA was isolated from the whole lung. Laser microdisection of tumors should be considered in future studies (57).

In summary, these data suggest that high intake of EPA and DHA from fish oil reduces prevalence of NNK-induced lung tumors in mice. This effect might be due to fish oil-up-regulated expressions of 15-LOX and p21 gene. Future studies should focus on the mechanism of fish oil-induced protective effect as well as on the intersection between diet and traditional chemotherapy, building on the cooperative effects seen in xenograft studies (58).

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Table 1

The effects of feeding different oils on mouse body weight[†]

Treatment group	Body weight at baseline (grams)	Body weight at sacrifice (grams)
Sham + control	19.86 ± 2.27	23.04 ± 2.71
NNK+ Control	19.84 ± 1.39	23.36 ± 1.98
NNK + Soybean Oil	19.89 ± 1.13	25.20 ± 2.88
NNK + Fish Oil	19.89 ± 1.72	22.99 ± 2.62
NNK + Corn Oil	19.84 ± 1.10	24.18 ± 3.48

[†]Means ± SD are shown, n = 13–14 animals per group (n = 14 animals per group for baseline body weight).

Table 2

The effects of oil supplementation on lung tumor measures[†]

Treatment group	Tumor Incidence	Tumors per Mouse
Sham + Control	0/13	0
NNK + Control	14/14 (100%)	15.50 ± 2.47
NNK + Soybean Oil	14/14 (100%)	14.14 ± 4.91
NNK + Fish Oil	14/14 (100%)	3.14 ± 1.56[*]
NNK + Corn Oil	14/14 (100%)	15.79 ± 2.55

[†] Means ± SD are shown, n = 13–14 animals per group;

[*] significant difference as compared with other oil-supplemented groups ($p<0.001$).

Table 3

The effects of oil supplementation on gene expression measures[†]

Treatment group	5-LOX	8-LOX	12-LOX	15-LOX	COX-2	p21
Sham + Control	1.13 ± 0.74	1.07 ± 0.39	1.04 ± 0.35	1.38 ± 1.91	1.08 ± 0.40	1.03 ± 0.31
NNK + Control	0.86 ± 0.23	2.47 ± 1.23	1.11 ± 0.39	1.98 ± 2.12	0.80 ± 0.37	1.14 ± 0.42
NNK + Soybean Oil	1.21 ± 0.42	2.78 ± 1.30	0.98 ± 0.26	0.60 ± 0.52	0.86 ± 0.26	1.27 ± 0.52
NNK + Fish Oil	1.10 ± 0.38	2.89 ± 1.41	1.45 ± 0.35[*]	3.55 ± 4.89[*]	0.70 ± 0.34	2.31 ± 0.74[*]
NNK + Corn Oil	1.08 ± 0.47	2.41 ± 1.06	1.07 ± 0.38	0.38 ± 0.28	0.75 ± 0.27	1.57 ± 0.48

[†]Means ± SD are shown, n = 13–14 animals per group;

[*]Significant difference as compared with NNK + Soybean Oil, isocaloric control ($p<0.001$).