Perspectives in Practice

The Content of Favorable and Unfavorable Polyunsaturated Fatty Acids Found in Commonly Eaten Fish

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ABSTRACT

Changes in diet during the past century have caused a marked increase in consumption of saturated fatty acids and n-6 polyunsaturated fatty acids (PUFAs) with a concomitant decrease in the intake of n-3 PUFAs. Increased fish consumption has been shown to be the only realistic way to increase dietary quantities of beneficial long-chain n-3 PUFAs such as eicosapentaenoic acid and docosahexaenoic acid and re-establish more balanced n-6:n-3 ratios in the diets of human beings. Our objective in this research was to characterize some of the relevant fatty acid chemistry of commonly consumed fish, with a particular focus on the four most commonly consumed farmed fish. To do this, 30 commonly consumed farmed and wild fish were collected from supermarkets and wholesalers throughout the United States. Fatty acid composition of samples from these fish was determined using gas chromatography. The 30 samples studied contained n-3 PUFAs ranging from fish having almost undetectable levels to fish having nearly 4.0 g n-3 PUFA per 100 g fish. The four most commonly farmed fish, Atlantic salmon, trout, tilapia, and catfish, were more closely examined. This analysis revealed that trout and Atlantic salmon contained relatively high concentrations of n-3 PUFA, low n-6:n-3 ratios, and favorable saturated fatty acid plus monounsaturated fatty acid to PUFA ratios. In contrast, tilapia (the fastest growing and most widely farmed fish) and catfish have much lower concentrations of n-3 PUFA, very high ratios of long chain n-6 to long chain n-3 PUFAs, and high saturated fatty acid plus monounsaturated fatty acid to PUFA ratios. Taken together, these data reveal that marked changes in the fishing industry during the past decade have produced widely eaten fish that have fatty acid characteristics that are generally accepted to be inflammatory by the health care community.

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Compelling evidence demonstrating the health benefits of n-3 polyunsaturated fatty acids (PUFAs) in fish together with dwindling supplies of fish caught from the wild have spawned a dramatic expansion in aquaculture (an annual rate of increase of 9.2% compared with 1.4% for captured fish) (1-3). Although a great deal of attention has been focused on the contamination of farmed fish populations with methyl mercury, polychlorinated biphenyls, and other organic compounds (4), little has been published with regard to the effects of rapid changes in the fish industry on PUFA or saturated fatty acid (SFA) levels in emerging, intensively farmed species of fish. Our research reveals certain intensively farmed species of fish contain PUFA profiles that have been shown to be detrimental to human health.

In the United States, tilapia has shown the biggest gains in popularity among seafood and this trend is expected to continue as consumption is projected to increase from 1.5 million tons in 2003 to 2.5 million tons by 2010, with a sales value of more than $5 billion (5). Based on this growth, tilapia is now the second (to farmed Atlantic salmon) most widely farmed fish in the world. Catfish has also seen explosive growth, from 0.3 million metric tons in 1994 to 0.7 million metric tons in 2003 (6). In contrast to the dramatic increases in farmed fish, wild salmon capture and wild tilapia capture has remained unchanged for the past 10 years (6).

The health benefits of the n-3 PUFAs in fish have been well documented (7). A meta-analysis examining fish consumption and coronary heart disease (CHD) in 13 cohort studies revealed an inverse relationship between fish consumption and CHD as well as sudden cardiac death, where each 20 g/day increase in fish consumption was associated with a 7% lower risk of fatal CHD (8). Long-chain n-3 PUFAs such as eicosapentaenoic acid (EPA) (also referred to as 20:5) and docosahexaenoic acid (DHA) (also referred to as 22:6) found in oily fish are thought to

be critical bioactive components that account for many of the health benefits of fish. The mechanisms responsible for their effects on cardiovascular disease and other complex diseases are likely to be multifactorial. Based on a large body of evidence collected during the past three decades, the American Heart Association (AHA) recommends that the general public eat at least two servings of fish per week, cardiovascular disease patients consume 1 g EPA+DHA per day, and patients with hypertriglyceridemia consume 2 to 4 g EPA+DHA per day (9).

The ratio of arachidonic acid (AA) to very long-chain n-3 PUFAs (EPA and DHA) in diets of human beings appears to be an important factor that dictates the anti-inflammatory effects of fish oils. Ingestion of fish or fish oil diets leads to a marked increase of EPA in membrane phospholipids and in some cases, a concomitant decrease in arachidonic acid. Wada and colleagues (10) recently reported that increasing the ratio of EPA to arachidonic acid in cellular phospholipids likely dampens prostanoid signaling with its largest effects on cyclooxygenase-1 involving the production of prostaglandin D, E, and F. Biochemical data from the laboratory of Serhan and colleagues (11) also predict that changes in arachidonic acid to EPA or DHA ratios shift the balance from proinflammatory prostaglandins, thromboxanes, and leukotrienes, to protective chemical mediators known as resolvins and protectins, which are proposed to play a pivotal role in resolving inflammatory response.

As discussed earlier, there have been dramatic changes in the fishing industry during the past decade, with fish virtually unknown 10 years ago now dominating the marketplace. Changes in fish consumption patterns raise important questions as to the effect of aquaculture on the quality and quantities of key very long-chain PUFAs that human beings ingest. Although there has been some evidence that aquaculture can cause modest changes in concentrations and ratios of PUFAs in Atlantic salmon, even that is not clearly established. For example, the US Department of Agriculture (USDA) database 20 reports that farm-raised Atlantic salmon contains more than 1 g dietary arachidonic acid per 100 g fish (12). If this is correct, farmed salmon is by far the richest source of arachidonic acid in most Western diets and raises important questions regarding its consumption, especially by vulnerable populations (12). The objective of this study was to determine the current status of the PUFA content in the most commonly eaten fish.

MATERIALS AND METHODS

Seafood Sources

Samples of a wide variety of fish were obtained in 2005 through seafood distributors on both the east and west coast (Poseidon Seafood, Atlanta, GA; Red Chamber Co, Vernon, CA; and Trident Seafoods Corp, Seattle, WA). Samples from these distributors are representative of fish that would be served in restaurants and available in supermarkets. In addition, farmed salmon were obtained directly from two Chilean companies, AquaChile and Camanchaca. This is particularly relevant because 60% of the farmed salmon obtained on the east coast is Chilean in origin (personal communication with Alex Trent, executive director, The Salmon of the Americas). Additional

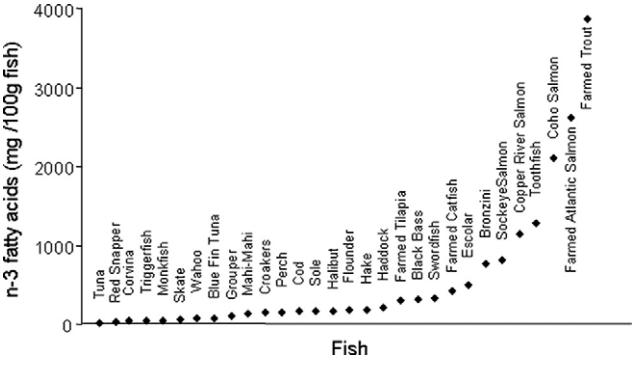

Figure 1. n-3 Fatty acid concentrations of common fish species. Concentrations of total n-3 fatty acids (18:3, n-3; 18:4, n-3; 20:4, n-3; 20:5, n-3; 22:5, n-3; 22:6, n-3) were determined using gas chromatography–flame ionization detection3 as described in the text. Concentrations in each fish are expressed as milligrams of total n-3 per 100 g wet weight fish. For all fish, (n=1), except: mahi mahi, cod, halibut, sockeye salmon (n=2); farmed tilapia (n=11); farmed catfish (n=8); farmed Atlantic salmon (n=16); and farmed trout (n=7).

samples of farmed tilapia, catfish, trout, and salmon were obtained from farms in Wisconsin, Idaho, North Carolina, Ecuador, Honduras, Norway, New Zealand, western Canada, and Chile and from supermarkets (Harris Teeter, Fresh Market, Lowes, Publix, Wegman's, and Winn Dixie) in Alabama, Florida, North Carolina, and Pennsylvania. Samples of canned fish were purchased from supermarkets locally (Winston-Salem, NC). The study was designed using availability sampling, as not all fish farms and fish distributors contacted were willing to provide samples for analysis. Because the availability of many fish is seasonal, restaurant distributors could only provide samples of fish currently in stock. All fish were shipped overnight on dry ice. To ensure the integrity of the tissue samples, all sections were immediately snap frozen in liquid nitrogen and stored at −80°C until analysis.

Study Design

An initial study was conducted to examine the fatty acid profile of 30 species of wild and farmed fish by gas chromatography–flame ionization detection (see Figure 1). Approximately 1 g sections of tissue were taken from each fish in duplicate and analyzed as described below. These fish were then analyzed based on their n-3 fatty acid content. For all fish species, n=1, except: mahi mahi, cod, halibut, sockeye salmon, where n=2; farmed tilapia, where n=11; farmed catfish, where n=8; farmed Atlantic salmon, where n=16; and farmed trout, where n=7. A second study was then conducted to more closely examine the fatty acid profile and ratios in the four most commonly farmed fish, Atlantic salmon (n=16), tilapia (n=11), catfish (n=8), and trout (n=7).

Fatty Acid Methyl Esters Analysis of Fish Samples

Approximately 1 g from each fish was weighed and homogenized in 10 mL/g deionized water at high speed for 60 seconds. An aliquot was taken for fatty acid methyl

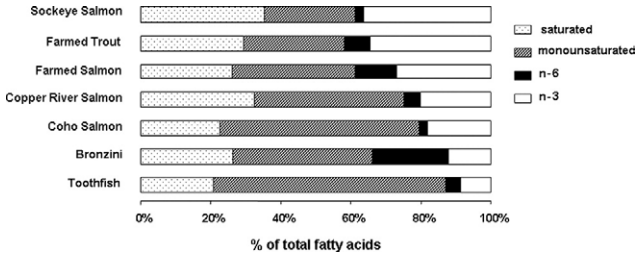

Figure 2. Percentage of fatty acids in fish containing >500 mg n-3 fatty acids/100 g fish. Concentrations of total n-3 polyunsaturated fatty acids (PUFAs) (18:3, n-3; 18:4, n-3; 20:4, n-3; 20:5, n-3; 22:5, n-3; 22:6, n-3), total n-6 PUFAs (18:2, n-6; 18:3, n-6; 20:3, n-6; 20:4, n-6), total monounsaturated fatty acids, and total saturated fatty acids were determined by gas chromatography–flame ionization detection. Fish are ordered based on their percentage of n-3 PUFAs. For all fish (n=1), except: farmed salmon (n=23), farmed trout (n=7) and sockeye salmon (n=2).

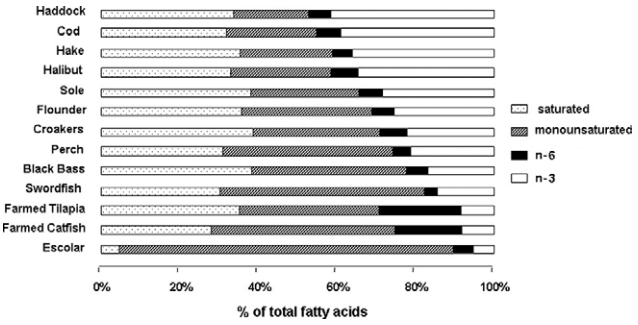

Figure 3. Percentage of fatty acids in fish containing between 150 and 500 mg n-3 fatty acids/100 g fish. Concentrations of total n-3 polyunsaturated fatty acids (PUFAs) (18:3, n-3; 18:4, n-3; 20:4, n-3; 20:5, n-3; 22:5, n-3; 22:6, n-3), total n-6 PUFAs (18:2, n-6; 18:3, n-6; 20:3, n-6; 20:4, n-6), total monounsaturated fatty acids, and total saturated fatty acids were determined by gas chromatograph–flame ionization detection. Fish are ordered based on their percentage of n-3 PUFAs. For all fish (n=1), except: farmed catfish (n=8), farmed tilapia (n=11), and halibut and cod (n=2).

ester analysis following a modification of the protocol by Metcalfe and colleagues (13). Tubes were prepared containing 25 μg triheptadecanoin (17:0) (Nu-Check Prep, Elsyian, MN) in hexane as an internal standard. Homogenates were saponified with ethanol and 50% potassium hydroxide at 60°C for 30 minutes. Following base hydrolysis, neutral lipids (ie, nonsaponifiable lipids) were extracted and discarded. A second hexane extraction resulted in isolation of the liberated fatty acids and fatty acid methyl esters were derived using 12% boron trifluoride in methanol. Fatty acid methyl esters were dissolved in isooctane.

Gas Chromatography–Flame Ionization Detection Conditions

The system consists of an HP 5890 Series II gas chromatograph (Agilent Technologies, Inc, Santa Clara, CA) with direct-on-column inlet, HP 7673 auto-injector (Agilent Technologies, Inc, Santa Clara, CA), FID, Varian Select for FAME (part no. CP7420, Varian, Inc, Palo Alto, CA) column (100 m×0.25 mm id) with a 1 m×0.53 mm id precolumn. Carrier gas (hydrogen) was at 20 psi head pressure, 1.25 mL/min at 90°C; carrier+make-up gas (nitrogen) at 20 mL/min. Temperature program was 90°C for 0.5 minute; 10°C/min to 150°C; 2.5°C/min to 200°C; 1.5°C/min to 220°C, hold 20 minutes. Total run time was 60 minutes plus a 5-minute equilibration. Component peaks were identified by retention time comparison to purified standards and standard mixtures. Data were reported as milligrams fatty acid per gram fish.

Statistical Analysis

Descriptive statistics, such as means, were calculated using Excel (version 11.8211.8202, 2003, Microsoft Corp, Redmond, WA).

RESULTS

n-3 PUFA

Initial studies were carried out to survey the n-3 concentrations and n-6: n-3 ratio of 30 commonly eaten fish. Figure 1 shows the concentrations of n-3 PUFAs per 100 g (approximately 3.5 oz) portion in these fish. As expected, there are marked differences in the concentrations of n-3 PUFAs in different species of fish, with the salmon and trout species having the higher concentrations of n-3s. Based on these initial data, fish species were divided into three categories; those that contained >500 mg (Category 1), those that contained between 150 and 500 mg (Category 2), and those that contained <150 mg n-3 fatty acids per 100 g fish (Category 3).

Category 1 Fish

Figure 2 and Figure 3 show the percentage of n-3 PUFAs, n-6 PUFAs, monounsaturated fatty acids (MUFAs), and SFAs in a given fish. Fish in each category have been arranged from highest to lowest percentages of n-3 PUFAs. All fish within Category 1 (Figure 2) with the exception of bronzini contained high concentrations of n-3 PUFAs relative to n-6 PUFAs. It is noteworthy that sockeye salmon contained both high concentrations of n-3 PUFAs and low concentrations of n-6 PUFAs resulting in a very favorable n-3 to n-6 ratio. Coho salmon, Copper River salmon, and farmed rainbow trout also contained beneficial concentrations and ratios of n-3 PUFAs and n-6 PUFAs. Although farmed Atlantic salmon contained high concentrations of n-3 PUFAs, they also contained much higher concentrations of n-6 PUFAs.

Category 2 Fish

Examination of Category 2 fish (containing between 150 and 500 mg n-3 per 100 g fish) revealed that most fish in this category also had favorable n-3 to n- 6 ratios with two notable exceptions (Figure 3). Both farm-raised tilapia and farm-raised catfish had considerably higher concentrations of n-6 PUFAs when compared to n-3 PUFAs. In both cases, this resulted in n-6 to n-3 ratios >2.

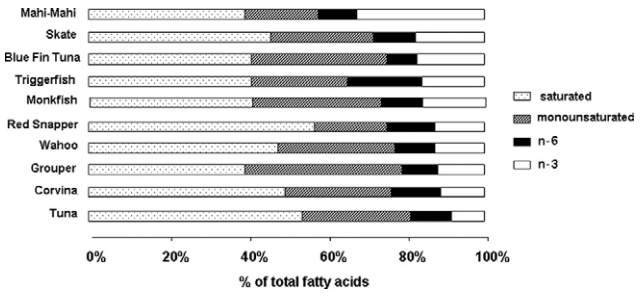

Figure 4. Percentage of fatty acids in fish containing <150 mg n-3 fatty acids/100 g fish. Concentrations of total n-3 polyunsaturated fatty acids (PUFAs) (18:3, n-3; 18:4, n-3; 20:4, n-3; 20:5, n-3; 22:5, n-3; 22:6, n-3), total n-6 PUFAs (18:2, n-6; 18:3, n-6; 20:3, n-6; 20:4, n-6), total monounsaturated fatty acids, and total saturated fatty acids were determined by gas chromatograph–flame ionization detection. Fish are ordered based on their percentage of n-3 PUFAs. For all fish (n=1), except mahi mahi (n=2).

Category 3 Fish

Fish in Category 3 (Figure 4) contained <150 mg n-3 per 100 g fish. Because of the relatively small concentrations of total PUFAs, these fish add less to dietary PUFA intake. Interestingly, although these contain relatively low concentrations of PUFAs, most of the fish within this category contain similar quantities of n-3 and n-6 PUFAs. Tuna, the second most consumed fish in the United States falls into this category and contains slightly more n-6 PUFAs relative to n-3 PUFAs (5).

Farmed Fish Comparisons

These initial observations raised questions as to the health benefits of the fatty acids in several commonly eaten fish and more specifically two intensively farmed fish, tilapia and catfish. To more directly address the question of levels of PUFAs in intensively farmed fish, additional samples of the most commonly consumed farmed fish—farmed salmon, tilapia, catfish, and trout—were gathered from major fish distributors and grocery stores in different geographic locations within the United States. Figure 5A illustrates the concentrations of n-3 PUFAs in individual samples from each of the four species. As expected from data shown in Figure 1, farm-raised salmon and trout contained the highest concentrations of n-3 PUFAs. In the case of trout, there was a great deal of variability depending on where the fish was acquired. This variability is also seen in tilapia and possible reasons are addressed below. There were relatively low concentrations of n-3 PUFAs in both tilapia and catfish. This is important because the vast majority of tilapia and catfish available for consumption in the United States is farmed, not wild.

Epidemiologic studies and clinical trials in both human beings and nonhuman primates have correlated SFA+MUFA:PUFA ratios with atherosclerosis progression and increased risk of cardiac events (14-16). Figure 5B shows this ratio in farmed salmon, tilapia, catfish, and trout. Whereas trout and salmon contain favorable ratios of <2, tilapia and catfish contain ratios of SFA+MUFA:PUFAs of approximately 4.

The ratios of n-6:n-3 PUFAs are shown in Figure 5C. As anticipated from results shown in Figure 2, both farm-raised Atlantic salmon and trout have ratios well below 1, whereas both tilapia and catfish have ratios >2. Total n-3 and n-6 PUFAs are often reported when assessing the health benefits of a fish. However, 18 carbon n-3 or n-6 PUFAs such as α-linolenic acid and linoleic acid, respectively, are poorly converted to very long-chain n-3 or n-6 PUFAs by human beings (17). Because 20 to 22 carbon very long-chain fatty acids are likely responsible for most of the biological activities attributed to fish, determining concentrations of very long-chain n-3 and n-6 PUFAs is most critical when considering the health benefits of fatty acids in given fish (11,18). Consequently, the ratios of the two primary 20 carbon n-6 and n-3 eicosanoid pathway substrates, arachidonic acid and EPA, were determined (Figure 5D). Both farmed tilapia and catfish contained high arachidonic acid:EPA. Although there was a great deal of variability in the arachidonic acid:EPA ratio in farm-raised tilapia, the average ratio was approximately 11:1, with two fish samples harvested in Central America containing more than 20 times more arachidonic acid than EPA. The ratio of PUFAs in these fish is high predominantly because they contain high quantities of arachidonic acid, with an average of 134 mg and 67 mg arachidonic acid for tilapia and catfish, respectively, with some tilapia samples from Central America containing >300 mg arachidonic acid per 100-g portion. To put this into perspective, a 100-g portion of hamburger (80% lean) contains 34 mg arachidonic acid, whereas a doughnut contains 4 mg arachidonic acid and 100 g pork bacon contains 191 mg arachidonic acid (19). For individuals who are eating fish as a method to control inflammatory diseases such as heart disease, it is clear from these numbers that tilapia is not a good choice. All other nutritional content aside, the inflammatory potential of hamburger and pork bacon is lower than the average serving of farmed tilapia. In contrast to tilapia and catfish, farm-raised salmon and trout contained low ratios of arachidonic acid to EPA (approximately 0.2), largely due to their high concentrations of EPA. These data with farmed salmon are consistent with a recent study by Hamilton and colleagues (12) and are in contrast to those reported by the USDA (19), which states that farm-raised Atlantic salmon contains much higher levels of arachidonic acid (1,152 mg/100g) and an arachidonic acid to EPA ratio of 1.9:1.

DISCUSSION

Taken together, these data raise important questions regarding the influence of aquaculture in changing the pattern of consumption of key fatty acids known to affect the health of human beings. The most rapidly expanding fish in terms of world and US consumption, tilapia, as well as farmed catfish, have several fatty acid characteristics that would generally be considered by the scientific community as detrimental. First, they have much higher SFA+MUFA:PUFA ratio than other farmed or wild fish. Ratios this high in diets have been shown to be directly associated with increases in SFA and MUFA in cholesterol esters of low-density lipoprotein particles and increased atherogenesis in both human beings and nonhuman primates (14-16). Although SFAs have long been

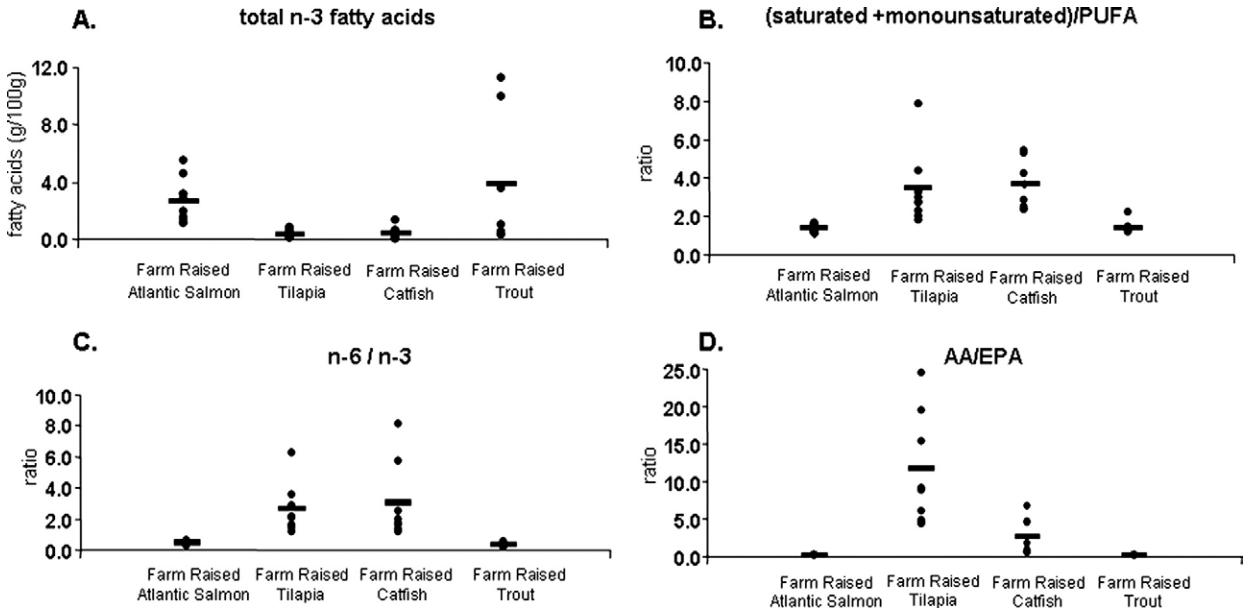

Figure 5. Concentrations of n-3 polyunsaturated fatty acids (PUFAs) (panel A), ratios of saturated+monunsaturated fatty acids to PUFAs (panel B), ratios of n-6 PUFAs to n-3 PUFAs (panel C), and ratios of arachidonic acid (AA) to eicosapentaenoic acid (EPA) (panel D) in common farmed fish. Concentrations of total n-3 PUFAs (18:3, n-3; 18:4, n-3; 20:4, n-3; 20:5, n-3; 22:5, n-3; 22:6, n-3), total n-6 PUFAs (18:2, n-6; 18:3, n-6; 20:3, n-6; 20:4, n-6), total monounsaturated fatty acids, and total saturated fatty acids were determined in the four most commonly consumed farmed fish in the United States by gas chromatography–flame ionization detection. Farm-raised Atlantic salmon (n=16), farm-raised tilapia (n=11), farm-raised catfish (n=8), and farm-raised trout (n=7).

associated with atherosclerosis, recent studies suggest that the desaturation of saturated fats such as stearate to oleic acid by stearoyl-coenzyme A desaturase appears to be an essential step in mediating the induction of obesity, insulin resistance, and dyslipidemia (20-23). Consequently, ratios this high would be predicted to induce, not protect from, diseases such as atherosclerosis.

Concerns Regarding Dietary Arachidonic Acid

The concentrations of n-6 PUFAs and more specifically the long-chain n-6 PUFA arachidonic acid in farmed tilapia and catfish are very high. In fact, these fish contain some of the highest levels of arachidonic acid found in human beings' food chain. There is a controversy among scientists in this field as to the importance of arachidonic acid or n-6:n-3 ratios vs the concentration of long-chain n-3 alone with regard to their effects in human biology (24,25). Harris and colleagues (26) have published several articles indicating that dietary arachidonic acid or n-6:n-3 ratios have no influence on CHD. This tenet is based on several lines of reasoning. First, an earlier study in 10 healthy male volunteers showed no proaggregation effects of high doses of dietary arachidonic acid and no effects on what the authors termed immune function (26). Second, a recent study showed that supplementation of a Japanese diet with 840 mg arachidonic acid had no effects on platelet function (27). Given the limitations of these studies, it is difficult to understand how either of these studies speaks to the issue of whether or not dietary arachidonic acid or ratios of long-chain n-6:n-3 fatty acids have an effect on disease progression in vulnerable populations. In the former study, dietary arachidonic acid caused more than four-fold increase in the ex vivo capacity of peripheral blood mononuclear cells from these volunteers to produce leukotriene B_4. Given the central role that leukotrienes play in the pathology of disease in human beings, especially inflammatory disease, this certainly questions the conclusion that there was no effect of arachidonic acid. In the latter study, arachidonic acid was fed to a Japanese population and fatty acid measurements of platelets in phospholipids or triglycerides were taken. The Japanese population consumes huge quantities of n-3 fatty acids each day from birth (>800 mg/day normally and >800 mg/day EPA+DHA in the study diet). Consequently, it would be predicted that the high concentrations of EPA already in platelet phospholipids would prevent a marked change in the arachidonic acid:EPA ratio or in platelet aggregation as a result of an increase in arachidonic acid. However, without platelet phospholipid data, it is not possible to make that determination.

The real question is whether or not dietary arachidonic acid affects disease progression in vulnerable populations. In this regard, several studies, including Neilson and colleagues (28-31), indicate that there is a strong in vivo correlation between arachidonic acid consumption and eicosanoid production. The first reported study of oral administration of highly enriched esterified arachidonic acid to human beings was carried out in 1975 at Vanderbilt University in John Oats' laboratory and demonstrated a marked increase in urinary prostaglandin E metabolites as well as a significant reduction in the threshold necessary to induce secondary, irreversible ag-

gregation of platelets (30). Most disturbingly, several individuals were removed from that study due to concerns regarding platelet reactivity. Other vulnerable populations markedly overproduce eicosanoids. For example, several polymorphisms related to leukotriene generation have been identified in asthmatic populations and a large proportion of asthmatics overproduce leukotrienes (32,33). Interestingly, these patients are 11 times more likely to respond to cysteinyl leukotriene blockers than asthmatics who do not overproduce leukotrienes (34,35). A more recent study by Dwyer and colleagues (36) demonstrated a strong association between a polymorphism in the 5-lipoxygenase gene promoter and an increase in intima-media thickness (a common measurement of cardiovascular risk). Interestingly, dietary arachidonic acid was associated with enhanced atherogenesis in this genotype. In contrast, increased dietary intake of EPA and DHA blunted this effect. The diet–gene interactions observed in these studies were specific to these fatty acids. Consequently, with respect to individual diseases, increases in arachidonic acid likely have different effects depending on the specific eicosanoids produced, the cell type that is activated, the disease in question and, as more recent studies are informing us, on the genotype of the individual afflicted.

Concerns Regarding the Use of Nutrition Databases to Assess Risk

A second argument that has been used to support the contention that dietary arachidonic acid or n-6 to n-3 ratios has little relevance are studies that have examined the relationship of either the fatty acid composition of various tissues acquired in the course of a number of studies or the fatty acid composition of food ingested from food frequency questionnaires to cardiovascular risk. In regard to the latter, the USDA National Nutrition Database is most frequently used to determine the fatty acid composition of foods. With regard to fish, if one scans the most recent version (Release 20) and examines farm-raised Atlantic salmon or tilapia, there were two and three data points, respectively, used to obtain the fatty acid quantities in the nutrient chart. It is not clear if these are analyses from one, two, or three fish. Most troubling is that farm-raised salmon is listed as having 1,150 mg arachidonic acid and 618 mg EPA per 100 mg portion. Our study taking duplicate samples from 28 fish throughout North America and the study by Hamilton and colleagues (12) that measured 459 farm-raised Atlantic salmon indicate that there is approximate five times more EPA than arachidonic acid in current stocks of farm-raised salmon and arachidonic acid concentrations are several-fold lower than indicated in Database 20. Indeed, this is good news for consumers who are ingesting farm-raised Atlantic salmon. The news is not so good with tilapia; here, Database 20 states there is 30 mg arachidonic acid per 100 mg in tilapia. However, our study shows that the amount of arachidonic acid depends largely on where the fish is obtained, with Central American tilapia containing as much as 10 times the 30 mg suggested by the USDA database. Because farm-raised Atlantic salmon and tilapia are major sources of fish for many individuals in the United States, using databases such as Database 20 to determine relationships of arachidonic acid to disease will likely lead to wrong conclusions. For example, using this database in a population that eats large amounts of farm-raised Atlantic salmon with resulting cardiovascular benefit will give the false impression that dietary arachidonic acid is beneficial in cardiovascular disease.

Metabolism of Cellular and Tissue Arachidonic Acid and EPA

Similarly, meta-analyses examining the relationship between tissue arachidonic acid levels and cardiovascular risk have been interpreted to show no relationship. However, the tissues analyzed have arachidonic acid ranges from <5% of total fatty acids to >25% of fatty acids. Even worse is the fact that some of the analyzed tissues are highly enriched in triglycerides and others in phospholipids. Biochemical studies have established that arachidonic acid is incorporated into triglycerides (via de novo glycerolipid biosynthesis) (37) and phospholipids (via arachidonic acid-phospholipid remodeling) by different mechanisms depending on the concentration of arachidonic acid presented to cells (38). In addition, arachidonic acid in different glycerolipids is located in different cellular pools and locations. Arachidonic acid in remodeled phospholipids is mobilized for eicosanoids (39) whereas arachidonic acid in triglycerides is not (40). Thus it is unlikely that simple analyses that place all arachidonic acid pools together will be able to predict with any precision whether dietary arachidonic acid is an important risk factor for disease in human beings.

Although the effect of altering the dietary ratio of arachidonic acid:EPA has yet to be determined, it is known that increasing EPA relative to arachidonic acid both in vitro and in vivo blocks prostaglandin formation from arachidonic acid by inhibiting cyclooxygenase-1 (41-43). In addition, cells such as platelets can convert EPA to thromboxane A_3 via cyclooxygenase-1 (44,45). EPA may also increase production of prostacyclin, which has been shown to diminish platelet aggregation (46). Another critical effect of increasing EPA:arachidonic acid is that it enhances the formation of prostaglandin E_3 (PGE_3) from EPA utilizing cyclooxygenase-2 (47,48). PGE_3 is thought to block inflammation, whereas arachidonic acid derived PGE_2 may promote inflammation. More recently, both EPA and DHA have been shown to be converted into anti-inflammatory mediators known as resolvins and protectins (11,18). Consequently, the ratio of arachidonic acid to long-chain n-3 PUFAs in diets of human beings is likely to be an important factor that regulates the balance of arachidonic acid and fish oil-derived eicosanoids produced.

How Did We Get Here?

There are several factors that may contribute to the marked differences observed in the fatty acid profiles of tilapia. Tilapia is a very hardy fish that grows rapidly on formulated feeds that contain lower protein levels, higher carbohydrate levels, and a wide range of fat sources compared with many other carnivorous farmed species (5). They are easy to breed and can be cultured intensively and economically in systems ranging from rural ponds to situations where the nutrition is exclusively dependent

on commercially formulated diets. Fish from the most intensively farmed system are typically fed higher levels of the 18 carbon n-6 fatty acid linoleic acid from vegetable oils as part of the feed (49). This, in turn, is efficiently converted through two desaturation steps and an elongation step to arachidonic acid that is found in tissues. Tilapia appears to represent an important example where an intensely farmed fish has a much higher content of SFA, MUFA, and linoleic acid leading to high concentrations of arachidonic acid and high n-6:n-3 ratios. Unfortunately, aquaculture, which holds such promise as a PUFA source from fish, can give rise to detrimental and potentially harmful PUFAs when fatty acid precursors of those PUFAs fed to fish are not taken into account.

Numerous clinical studies have been conducted with the conclusion that increased fish consumption reduces the risk of CHD (50). In addition, the AHA recommends that individuals consume fish at least twice per week. Although the AHA does specify fatty or oily fish as preferable, specific types of fish are not highlighted as especially healthful or especially unhealthful. Without being given certain fish to either look for or avoid, the general population is likely to purchase the fish that is most readily available at the supermarket, or the fish that costs the least. Farmed tilapia certainly fits into both categories. Since 2000, shipments of frozen tilapia fillets from China to the United States (representing 66% of imports) have risen from 4 million to 140 million lb. Chinese frozen tilapia fillets averaged $1.38 per lb in 2006, about even with the previous 2 years (51). Although convenience and price will clearly be important drivers in the marketplace, our study shows that the drastically different nutrition profiles must be taken into account when deciding on or recommending fish to consume.

This study has several limitations. First, although fish were sampled from a wide variety of sources throughout the United States and other countries, it would be impossible to sample fish from every source worldwide. Notably absent from this study are fish from Asian and European sources. In addition, the analyses focus on fish that are commonly eaten in the United States, whereas fish often eaten in other parts of the world may have been neglected from the study. A final limitation of this study is that the sampling of fish was not random. The sampling was based on which species were available and which distributors were willing to provide samples for analysis. Although every effort was made to sample fish from a wide variety of geographical locations, it was not possible to sample all locations and fish species equally.

Can Tilapia Offer Public Health Benefits or Harm?

Despite recommendations from organizations such as the AHA to increase fish consumption in general, this study shows that not all fish are created equal. The initial overview of fish alone shows that there is a range of n-3 fatty acid content from practically none to nearly 4,000 mg per 100 g fish. Closer inspection of the four most commonly farmed fish, Atlantic salmon, tilapia, catfish, and trout, reveals yet another discrepancy in the general ideal that it is healthful to eat fish. Whereas farmed Atlantic salmon and farmed trout have some of the highest levels of n-3 fatty acids, combined with low levels of arachidonic acid, farmed tilapia and catfish have low levels n-3 fatty acids along with levels of arachidonic acid so high they can be considered detrimental. Taken together with tilapia's explosive growth and its relatively inexpensive price at best gives vulnerable populations a false sense of security in their dietary choices and at worst renders them more vulnerable. Clearly it is necessary to educate the population on the health differences between species of fish to negate the widely held belief that eating any fish is beneficial.

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