The nutritional significance of fish lipids

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In all fish commonly used as food the predominant lipid is triglyceride fat. There are species which contain, in the flesh or elsewhere, lipids largely other than true fat. Thus, the flesh lipid of the castor-oil fish (*Ruvettus pretiosus*) is a wax and the liver lipid of certain sharks is mainly alkoxydiglycerides or squalene or both. But such biochemically interesting variants have no significance in human nutrition since the fish tissues in question are not normally eaten. There are, however, two lipids of widespread occurrence in fish which, although very minor constituents on a weight basis, cannot be ignored nutritionally. These are vitamins A and D. I shall confine my attention to the significance in human nutrition of the triglyceride fat and of the vitamins A and D of fish.

Contribution of fish fat to energy requirements

The quantitative significance of fish fats in human nutrition is obscured by several factors, including the dietary habits of the particular people involved. Certain fish, e.g. cod, deposit virtually the whole of their depot fat in the liver, which amounts to about 5% of the live weight of the fish and may contain up to 75% of fat. If cod liver is consumed as food, as it is in certain parts of the world, it clearly contributes heavily to the caloric intake of anyone who eats appreciable quantities of it. For most British residents, however, unless they regularly take cod-liver oil for medicinal purposes, cod does not furnish any dietary fat at all. With other types of fish, e.g. herrings, sprats or mackerel, virtually the whole of the fat is stored in the flesh and a meal of such a species inevitably contributes appreciable calories from fish fat. One herring weighing, say, 150 g may contain 20 g fat, predominantly in the edible portion. Canned fish consist overwhelmingly of species which store their fat in the flesh, e.g. herrings, sardines, pilchards, anchovies, salmon, tunny. Such products will, on the average, contain about 10% fish fat, quite apart from the vegetable oil sometimes added.

In all species of fish there is considerable variation in the total fat content, largely associated with spawning and with seasonal variations in intensity of feeding. Spawning may reduce the fat content of cod livers from 75 to about 40%. In the herring, the most important British oily-fleshed fish, the fat content varies from less than 1% to over 22% (Lovern & Wood, 1937). A curious example of variation is found in the common eel (*Anguilla vulgaris*) where, at any rate over a certain range, the percentage of fat in the flesh is proportional to the length of the fish (Lovern, 1938). Thus, eels 12, 18 and 24 in. long contain about 8, 17 and 30% of fat respectively.

Some idea of the direct contribution of herring fat to the total British diet can be obtained from the 55,000 tons of herrings eaten in this country in 1956 (Herring

Industry Board, 1956). Assuming conservatively an average oil content of 10%, we get about 2750 tons of oil in the edible portion, or about 0·15 g/head/day over the entire population. This negligible figure does not, of course, reflect the position of those individuals who actually eat herrings or kippers regularly. The position in other parts of the world could only be assessed after careful consideration of local dietary habits and species of fish.

A large proportion of the total world catch of oily species of fish is not used directly for human food, but is converted into animal feeding-stuff and free oil. The latter is partly used for non-food purposes and partly hydrogenated for use in human food. In Britain the domestic production of herring oil was 3300 tons in 1956 (Herring Industry Board, 1956). Most of this oil would be hydrogenated and blended into edible fats, but the daily amount per head of the population is only about 0·18 g. In contrast to herrings eaten directly, consumption of the hydrogenated fat will be fairly evenly distributed. The conclusion is inescapable that, apart from individuals and local areas, fish fats contribute little to the world's supply of calories.

Fish fats and essential fatty acids

Certain fatty acids are recognized as essential dietary ingredients for various species of animal, almost certainly including man. This whole subject formed the theme of the Fourth International Conference on the Biochemical Problems of Lipids, in Oxford in 1957, which should soon be published. The well-recognized acids of this group are linoleic, linolenic and arachidonic. The animal can convert linoleic acid into arachidonic acid, in which form it probably exerts its specific effects. Linolenic acid cannot be converted by the animal into arachidonic acid, but possibly becomes a pentaenoic (Steinberg, Slaton, Howton & Mead, 1957) or a hexaenoic acid (Holman, 1956*a*). Linolenic acid is far less effective in relieving signs of deficiency of essential fatty acids, both qualitatively and quantitatively, than are linoleic or arachidonic acids (*cf.* Deuel, 1955). The interrelation of polyunsaturated fatty acids is easier to visualize if we abandon the accepted method of numbering the carbon atoms from the carboxyl end and count instead from the terminal methyl carbon. Biological chain lengthening or shortening is effected at the carboxyl end, the rest of the chain remaining little affected. Following Klenk's practice (e.g. Klenk & Tomuschat, 1957), we may consider at least three series of acids, the oleic, linoleic and linolenic series, according to whether the first double bond is between carbons 9 and 10, 6 and 7 or 3 and 4, counting from the terminal methyl carbon. This and the conventional system are compared in Table 1, where it can be seen that arachidonic acid belongs to the linoleic series.

Table 1. *Position of double bonds in oleic, linoleic and linolenic acids*

Acid	COOH as carbon 1	CH_3 as carbon 1
Oleic	9	9
Linoleic	9, 12	6, 9
Linolenic	9, 12, 15	3, 6, 9
Arachidonic	5, 8, 11, 14	6, 9, 12, 15

Fish fats do not contain appreciable proportions of linoleic or linolenic acids (Hilditch, 1956) and it is uncertain whether arachidonic acid is a significant component. Those polyunsaturated fatty acids of fish fats that have been satisfactorily characterized are, predominantly, eicosapentaenoic and docosahexaenoic, with smaller proportions of octadecatetraenoic and traces of a hexadecatetraenoic acid. Much more work must be done before we can say just what polyenoic fatty acids are present in fish fats, and in what proportions. The acids definitely identified are listed in Table 2. Apart from the trace component C_{16} tetraene, which does not belong to the oleic, linoleic or linolenic series, the acids belong to the linolenic series. Hence their essential fatty-acid activity would be expected to be low, probably similar to that of linolenic acid. The results of Thomasson (1953–4), with whole fish oils (cod-liver, menhaden and herring) rather than constituent acids, show this to be so.

Table 2. *Position of double bonds in polyenoic fatty acids of fish oils*

Fish	Acid	COOH as carbon 1	CH_3 as carbon 1	Reference
Pilchard	Hexadecatetraenoic	6, 9, 12, 15	1, 4, 7, 10	Silk & Hahn (1954)
Herring	Octadecatetraenoic	6, 9, 12, 15	3, 6, 9, 12	Klenk & Brockerhoff (1957)
Pilchard				Whitcutt (1957*a*)
Pilchard	Eicosapentaenoic	5, 8, 11, 14, 17	3, 6, 9, 12, 15	Whitcutt & Sutton (1956)
Cod				Klenk & Eberhagen (1957)
Pilchard	Docosahexaenoic	4, 7, 10, 13, 16, 19	3, 6, 9, 12, 15, 18	Whitcutt (1957*b*)

The human requirement for essential fatty acids is not known but Holman (1956*a*), from animal experiments, considered that linoleic acid equivalent to 1% of the calories should be adequate, say 3 g daily. Clearly fish fats again cannot make any significant contribution to the total population needs of this country or of the world. One herring furnishes at least 5 g polyethylenic fatty acids equivalent for growth, but not for all purposes, to about 0·5 g of linoleic acid.

Fish fats and blood lipid levels

The role of dietary fat in raising or lowering the level of blood cholesterol (and blood phospholipids) is a rather controversial topic and even more so is the possible significance of these blood lipid levels in the aetiology of atherosclerosis and coronary thrombosis. Accepting for present purposes that low levels of blood cholesterol are desirable, we may consider the dietary significance of fish fats in this respect.

In contrast to the essential fatty-acid story, there is no evidence that position of double bonds has any significance for blood lipid levels. What seems fairly well established is that relatively saturated dietary fats tend to raise the level of blood cholesterol whereas relatively unsaturated fats tend to lower it. The simple iodine value of a fat may be a good index of its probable effect on blood lipids (Ahrens, Hirsch, Insull, Tsaltas, Blomstrand & Peterson, 1957). A more specific claim is that ingested saturated fatty acids raise the level and polyunsaturated fatty acids lower the level of blood cholesterol, monoethylenic acids having little effect (Keys, Anderson & Grande, 1957). It may be noted that blood cholesterol is esterified overwhelmingly with polyunsaturated acids and with an unusually low proportion

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of saturated acids (Lough & Garton, 1957). Holman (1956*b*) suggested that polyunsaturated fatty acids are necessary for the normal transport of cholesterol.

On either basis fish fats should lower blood cholesterol levels. Their mean iodine value is exceptionally high and they have a fairly low content of saturated acids together with a high content of polyunsaturated acids. Experimentally there is no controversy. Fish oils resemble the more unsaturated type of vegetable oil in tending to lower blood cholesterol levels. Findings to this effect with human subjects have been reported by Bronte-Stewart, Antonis, Eales & Brock (1956) and by Keys *et al.* (1957), and similar effects have been reported for whale oil (Malmros & Wigand, 1957) and seal oil (Bronte-Stewart *et al.* 1956; Harlow, 1957), which have fatty-acid compositions generally like those of fish fats. The practical significance of these findings depends on the amount of fat-rich fish habitually consumed by any individual, in relation to the rest of his dietary fat intake. Clearly once again the overall national or world picture must be one of negligible significance. Fish may be used to improve the rather monotonous diet sometimes prescribed for atherosclerotic patients (Ahrens *et al.* 1957; Malmros & Wigand, 1957; Nelson, 1957).

Vitamins A and D in fish

Some species of fish furnish the richest known food sources of vitamin A or D or both. Though the synthetic compounds have largely replaced fish products in food-fortification programmes, there are still many people for whom fish furnish the main supply of these two vitamins. Since both can be stored in the body for lengthy periods, it is the total consumption over a period that matters. I do not propose to tabulate any data on the vitamin A and D content of various tissues and species of fish. Kühnau (1956) has collected a wealth of such data and it should suffice to discuss its general dietary significance.

The enormous variation in vitamin content of any particular tissue from species to species should be noted. This variation may be from nearly nil to extremely high values. Thus, haddock liver may contain only about 0·002% of vitamin A (66 i.u./g), cod liver may have ten times and halibut liver up to a thousand times as much (Edisbury, Morton, Simpkins & Lovern, 1938). Some species of shark have livers outstandingly rich in vitamin A, up to about 6% (200,000 i.u./g), whereas other sharks are very poor in vitamin A. The liver is often not the only major depot for vitamin A in fish, a common one in many species being the intestine and pyloric caeca. In the halibut, for instance, these organs contain about as much total vitamin A as the liver, and certain portions of the tissue contain up to about 3% of vitamin A (Lovern & Morton, 1939). Variations in tissue fat and vitamins are naturally reflected in the pharmaceuticals prepared from them, e.g. halibut intestine, halibut liver and shark liver contain about 5, 20 and 75% respectively of total lipid and the first, therefore, often gives the most potent 'oil'. By selection of tissue it is possible to prepare halibut intestinal 'oil' containing about 30% of vitamin A, a figure only exceeded in my experience by a sample of swordfish-liver oil containing 40% of vitamin A. The flesh of most fish is virtually devoid of vitamin A but the freshwater eel is outstanding with up to 45 i.u./g. The conger eel seems to contain appreciably lower but still significant proportions, the one specimen examined by Edisbury *et al.* (1938) having about 12 i.u./g in the flesh.

Similar extensive variations are found for vitamin D, except that all sharks and other cartilaginous fish are almost devoid of it. Average values for cod- and halibut-liver oils are about 100 and 3000 i.u./g and liver oils ranging up to 300,000 or more i.u./g have been reported for the bonito. A more usual value for the richest species is about 50,000 i.u./g liver oil. The flesh of the so-called white fish, e.g. cod, is virtually devoid of vitamin D but that of oily fish contains significant amounts, e.g. about 10 i.u./g in herring (Bacharach, Cruickshank, Henry, Kon, Lovern, Moore & Morton, 1942). One herring may provide about 700 i.u. vitamin D in the edible portion. Again the freshwater eel is valuable, its flesh containing about 15 i.u./g. As Edin & Scheller (1943) comment, 100 g of eel flesh contains as much vitamin D as 3 teaspoonfuls of cod-liver oil.

In all species and tissues there are considerable variations in the content of vitamins A and D between individuals. One factor is age, older fish tending to have higher reserves of both vitamins. In some species seasonal variations may be enormous, e.g. for vitamin A in halibut liver (Lovern, Edisbury & Morton, 1933).

The nutritional significance of vitamins A and D from fish cannot be averaged over a national or world population. Those who regularly take fish-liver oil medicinally may well derive the major part of their total intake of both vitamins from it. In areas where fish liver is commonly eaten, the same will apply. The total landings of white fish in the United Kingdom are equivalent to about 20,000 tons of liver oil, mainly from cod and similar species. If this were all available for human use it could provide about 1000 i.u. vitamin A and 100 i.u. vitamin D/head/day. The total current British consumption of herrings (55,000 tons in 1956) would, if evenly spread over the population, provide about 25 i.u./day vitamin D. In reality the conclusion must be that those individuals who fairly frequently eat herrings or similar fish, e.g. sardines, obtain quite a high intake of vitamin D from this source. The epicure who enjoys eels gets a meal unusually rich in calories, in polyunsaturated fatty acids and in vitamins A and D.

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