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Dioxins and polychlorinated biphenyls (PCBs) in fish oil dietary supplements: Occurrence and human exposure in the UK

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Key-Words – Dioxins, PCDD/Fs, PCBs, fish oil, WHO-TEQ, ICES-7 PCBs

Abstract

Commercially available fish oil supplements sourced from retail outlets in the UK, as well as by mail order, were surveyed in 2001-2 for dioxin (PCDD/Fs) and PCB content. Sampled products were representative of market share. The WHO-TEQ values for these products ranged from 0.18 – 8.4 ng/kg for Σ PCDD/F and 1.1 – 41 ng/kg for Σ dioxin-like PCBs. The results suggest a downward trend in the levels of dioxins in fish oil supplements over the last decade, since levels for similar products ranged from 0.3 – 10 ng/kg for Σ PCDD/F WHO-TEQ in 1996. Levels of ICES (International Council for the Exploration of the Seas) 7 PCBs in the current study ranged from 8.3 – 267 μ g/kg. Subsequent to this survey, EU legislation has been introduced that includes a maximum limit of 2 ng/kg WHO-TEQ for dioxins in fish oil products for human consumption. 12 of the 33 products reported here would have exceeded this limit. Negotiations are in progress to incorporate dioxin-like PCBs into the EU regulations.

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When manufacturer-recommended doses were applied to the observed levels, the estimated upper bound human exposure to dioxins and dioxin-like PCBs from dietary

1 intake of these products ranged from 0.02 to 7.1 pg WHO-TEQ/ kg bodyweight/ day
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3 for adults and 0.02 – 10 pg WHO-TEQ/ kg bodyweight/ day for school children. This
4
5 level rises to 1.8 – 8.9 pg WHO-TEQ/ kg bodyweight/ day for adults and 1.4 – 14 pg
6
7 WHO-TEQ/ kg bodyweight/ day for school children when combined with average
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9 exposure from the whole diet in 1997. Again subsequent to this survey, the
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11 Committee on Toxicity of Chemicals in Food, Consumer Products and the
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13 Environment (COT) revised the UK TDI for mixtures of dioxins and dioxin-like
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15 PCBs from 10 pg WHO-TEQ/kg bodyweight per day to 2 pg WHO-TEQ/kg
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17 bodyweight/day. This is in line with the Tolerable Weekly Intake of 14 pg WHO-
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19 TEQ/kg bodyweight set by the Scientific Committee on Food.
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24 Introduction

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26 Fish oils derived from the liver or tissue (body oil) of cold-water fish species such as
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28 cod, salmon, halibut etc. have enjoyed widespread use as dietary supplements and
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30 licensed medicines. These products are commercially available at retail outlets and by
31
32 mail-order and are commonly sold either as capsules, liquid oils or as oils in
33
34 combination with more palatable diluents such as fruit syrups. Fish oils are known to
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36 be a source of Vitamins A and D, as well as long chain fatty acids, particularly
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38 Omega-3 fatty acids.
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41 Over the last two decades, the popularity of these products has increased concurrently
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43 with scientific research that has investigated the benefits of these oils in addressing a
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45 number of human maladies, including cardiovascular disease, stroke, high blood
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47 pressure, renal injury, rheumatoid arthritis and autoimmune disorders (Tran 2001,
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49 Mori et al. 1994, Donadio et al 1994, Schmitz et al 2002, Mason P 2000). At least
50
51 some of the benefits of fish oils are thought to be due to the long chain n-3
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53 polyunsaturated fatty acids (LC n-3 PUFA), eicosapentaenoic acid (EPA) and
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docosahexaenoic acid (DHA), the presence and levels of which are increasingly being included on the labels of fish oil products. The latter compound is essential for the development of the central nervous system, whilst the former is used by the body to produce prostaglandins and is also incorporated into cell lipids, including those in the cell membrane. In recent years, these products have been specifically targeted towards children suffering from dyslexia, dyspraxia, attention-deficit hyperactivity disorder (ADHD) and other similar disorders.

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One of the main non-clinical disadvantages of using fish oils as dietary supplements, which has emerged in recent years, is the presence of environmental contaminants in these products. The natural habitat of these fish species – the continental shelf specially around the North Sea and the Atlantic Ocean, has experienced the build-up of persistent organic contaminants such as PCBs, dioxins, polybrominated diphenylethers (PBDEs), polycyclic aromatic hydrocarbons (PAHs) and various pesticides through atmospheric deposition, run-off and pollution from shipping. This has resulted in an enrichment of these pollutants, particularly in coastal sediments and, consequently, in the marine food chain. Many fish species bio-accumulate these contaminants, which are lipophilic and thus associate with lipid-rich tissues such as the liver and oil-rich muscle. As noted earlier, fish oil dietary supplements are produced from such tissues and the initial crude product can contain very high levels of these contaminants. The actual concentrations observed are dependent not only on the species but also on the geographical location (Brevik et al. 1990), with products sourced from the Southern Hemisphere generally showing lower levels of environmental contamination than those from Northern Hemisphere locations such as parts of the North Sea and especially the Baltic Sea, which is very contaminated with dioxins. The age of the fish and type of tissue used may also influence the

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contaminant levels, with data suggesting that oil derived from the liver is often more contaminated than muscle tissue oil.

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In an effort to remove these contaminants, the industry employs a number of refining processes. General refining may include processes such as odour removal by steam stripping, exclusion of high molecular weight compounds by cold filtration, and removal of other undesirable contaminants by activated charcoal filtration, as well as other chemical methods (Brevik et al. 1990). However, molecular distillation (using a temperature range of 180 – 220⁰C at < 100Pa) is far more effective at removing halogenated contaminants, especially PCBs. A drawback of some of the refining processes is that beneficial components of the fish oils, such as EPA and DHA, are removed at the same time as the contaminants, and the refining process employed must therefore strike a balance between contaminant removal and omega-3 fatty acid retention. Thus, some manufacturers have invested in developing newer (undisclosed) purification methods that are able to achieve this balance and are claiming success. An alternative means of reducing the dietary exposure to consumers but without further purification is, of course, to reduce the manufacturer recommended dosage, especially for children.

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The last survey of fish oil dietary supplements for PCBs and dioxins, carried out by the Ministry of Agriculture, Fisheries and Food in the UK in the mid-1990s, studied levels of these contaminants in retail products purchased in 1994 and 1996. Combined (dioxin plus dioxin-like PCB) concentrations for cod liver oils ranged from 7.3 - >44 ng WHO-TEQ/kg in 1994 and from 18 – 41 ng WHO-TEQ/kg in 1996 (MAFF 1997). The Tolerable Daily Intake (TDI) at the time was 10 pg I-TEQ/kg bodyweight/day, and a typical consumer taking the manufacturer recommended dose

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1 would not have exceeded this level except in the case of toddlers (because of low
 2 body mass). In combination with the whole diet in 1997, however, all groups would
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 4 have exceeded the upper end of the 1998 WHO recommended TDI range of 1-4 μ g
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 6 WHO-TEQ/kg bw/day (Leeuwen and Younes, 2000).
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 11 Those findings were followed by discussions between the regulators, the Department
 12 of Health, the Medicines Control Agency and representatives of the fish oils industry
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 14 in the UK with the aim of exploring measures that would help to reduce the dioxin
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 16 and PCB exposure from fish oil-based dietary supplements. This study represents
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 18 continued monitoring of dioxin and PCB levels in fish oil dietary supplements. It will
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 20 demonstrate the effectiveness of improved purification procedures employed by
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 22 manufacturers as well as establish current levels in these products within the UK.
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27 Sampling and Analysis

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 29 A total of 33 dietary supplement products, comprising mostly cod liver oils but also
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 31 salmon oils, other fish oils and formulations of cod liver oil with orange syrup, or
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 33 lemon flavouring, were purchased from retail outlets and by mail order during 2001-
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 35 02. It was assumed that sampling would be representative, as these products are
 36
 37 distributed nationally across the UK. Products that were sampled in previous surveys
 38
 39 in the UK (MAFF 1997) were included where they were still available for purchase,
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 41 along with a number of additional products. On receipt at the laboratory, each sample
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 43 was given a unique laboratory reference number and the sample details logged into a
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 45 database.
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50 Product expiry dates were checked to ensure validity of the shelf-life of the samples
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 52 during the measurement period. Information on recommended dosage provided on
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1
2 the product labels was recorded, together with any other relevant sample details,
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4 Samples were stored sealed in their original containers at ambient temperature prior to
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6 analysis. Where samples were sold as capsules, the casings were excluded from the
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8 analytical sample.
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11 The method used for the extraction and analysis of samples have been reported
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13 previously (Fernandes et al. 2004 a). In brief, samples were fortified with ¹³C-labelled
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15 analogues of target compounds and exhaustively extracted using mixed organic
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17 solvents. *Ortho* substituted PCBs were separated from non-*ortho* substituted PCBs
18
19 and PCDD/Fs by fractionation on activated carbon. The two fractions were further
20
21 purified using adsorption chromatography on alumina. Analytical measurement was
22
23 carried out using high resolution gas chromatography/ high resolution mass
24
25 spectrometry (HRGC-HRMS) for the PCDD/Fs and non-*ortho* substituted PCBs
26
27 (IUPAC Nos. 77, 81, 126 and 169) and high resolution gas chromatography/ low
28
29 resolution mass spectrometry (HRGC-LRMS) for the *ortho* substituted PCBs (IUPAC
30
31 Nos. 18, 28, 31, 47, 49, 51, 52, 99, 101, 105, 114, 118, 123, 128, 138, 153, 156, 157,
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33 167, 180, 189).
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39 All analyses and results were UKAS accredited to ISO 17025 standards. Sample
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41 batches included a blank and the following BCR (Bureau of community reference)
42
43 reference materials: CRM 350 (mackerel oil) for PCBs and RM 534 (milk) for the
44
45 PCDD/Fs. Further quality assurance measures included the successful participation,
46
47 during the course of this study, in international inter-comparison exercises (FAPAS
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49 2002, Dioxins in Food, 2000, Dioxins in Food 2001) on dioxins and dioxin-like
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51 PCBs, which included cod liver and cod liver oil among the test matrices.
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Results and Discussion

All of the samples that formed part of this study showed detectable levels of PCDD/Fs and PCBs apart from one cod liver oil sample in which the PCDD/Fs were below detection limits. The reporting limit quoted for non-ortho-PCBs and dioxin congeners was the limit of determination that prevailed in that instance. The limit varied for different congeners but, at its lowest value, was 0.02 ng/kg fat. For the ortho-PCBs, a reporting limit of 0.10 µg/kg fat was applied.

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Insert Table 1 here

Summary data for all individual samples, presented as Σ WHO-TEQ for each class of PCDD/Fs, non-ortho-PCBs, and ortho-PCBs, as well as total Σ PCDD/F+PCB WHO-TEQ, is presented in Table 1. Details of the origin and brand of the products is given elsewhere (FSA 2002). The Σ ICES 7 PCBs is also included. The WHO-TEQ data were calculated using the appropriate WHO-TEF values (Van den Berg et al. 1998) and summed to give Σ WHO-TEQ (all WHO-TEQ data quoted in this work has been calculated in this way). Data are reported as upper-bound, which means that, in cases where congeners were not detected, they were assumed to be present at a concentration equivalent to the detection limit. As most of the samples in this survey were oils, whole weight basis TEQs would be equivalent to the fat weight basis data and have therefore not been reported separately. One sample that was a mixture (of unspecified proportions) of cod liver oil and orange syrup has been excluded from the statistical analysis which is shown in Table 2.

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Insert Table 2 here

These data show that the major contribution to the total Σ WHO-TEQ comprises the PCBs, with approximately 55% from the non-ortho-PCBs and 24% from the ortho-

PCBs, the remainder coming from the PCDD/F contribution. This is in agreement with observations on fish oil and fish in general, as reported by other workers (Fernandes et al 2004b, Falandysz et al 1994, Jiminez et al 1996, Jacobs et al 2002 CFIA 2004, Bordajandi et al 2000, MAFF 1999). In particular, when compared to another contemporaneous survey of fish oils commissioned by the Food Safety Authority of Ireland (FSAI, 2002), the contribution from PCDD/Fs to the Σ WHO-TEQ is the same, at 21% (Table 3). The data are not directly comparable with the UK data. The apparent differences between the countries are largely due to the range and relative quantities of products and brands surveyed. In the UK survey, twelve of the 32 samples are derived from a single manufacturer's product. These samples showed consistently lower TEQ levels than the majority of other fish oil supplements. The Irish survey, on the other hand, only contains one sample of this product. Consequently, the UK data show a much higher proportion of lower concentrations compared to the Irish data. Therefore, the UK data has a lower mean and median, and is more skewed. The Irish data shows a much more even distribution with good agreement between the mean and median values and a very low skewness. Nevertheless, the results for the two countries are broadly similar. Both sets of data are positively skewed, and the observed TEQ levels are of the same order of magnitude. The distributions for both sets of PCB WHO-TEQ data are shown in Figure 1, which gives histograms for both sets of data.

Insert Table 3 here

Insert Figure 1 here

The congener profiles for samples in this study are generally similar with the PCDD/Fs dominated by the presence of 2378-TCDF, and with a few samples showing higher levels of OCDD. Among the PCBs, 77 and 126 show the highest levels of occurrence among the non-ortho PCBs and the ICES 7 congeners (particularly 101,

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Deleted: -11 ng/kg WHO-TEQ for the Irish results). Both sets of data are positively skewed, although the UK data show a much higher proportion of lower concentrations (median 0.9 ng/kg WHO-TEQ) compared to the Irish data, which show similar mean and median values (3.6 and 3.2 ng/kg WHO-TEQ respectively). However, data for the PCB TEQ show slightly different ranges with a lower range of 0.2 – 29.8 for the Irish data compared to 1.1 – 41.5 ng/kg PCB TEQ. These lower values can be ascribed to the greater proportion of samples of products with lower concentrations in the UK survey. [DN: This last sentence doesn't seem to follow] This view is supported by the lower median value of 4.8 ng/kg and a skewness value of 1.7. The Irish data, on the other hand, show a much more even distribution with good agreement between the mean and median values and a very low skewness. Both sets of data will, however, be influenced by the variation in the range of products and brands surveyed, and the data sets are therefore more notable for their similarity rather than their differences.

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118, 138 and 153) dominate the ortho substituted PCBs. In general these observations are similar to those observed in other studies (Jacobs et al, Sandell and Kokkenen, FSAI 2002b). A more detailed assessment within individual analyte groups shows that in order of contribution, PCB 126 is the largest contributor to total Σ WHO-TEQ followed by PCB 118 and PCB 156. 1,2,3,7,8-PeCDD, 2,3,4,7,8-PeCDF, 2,3,7,8-TCDD and 2,3,7,8-TCDF also make significant, though smaller contributions. It must be emphasised that these observations refer to the fish oil data in the group of samples discussed in this paper and may reflect the effects of the purification procedures used by manufacturers, rather than the original contaminant levels in the oil. An important implication that follows is that the reduction in levels observed in this data set compared to previous data may be the result of better purification procedures or more selective sourcing of products based on geography, rather than actual reductions in the levels of contamination in the crude oil products. This view needs to be balanced with the observations on gradually declining dioxin and PCB levels in fish in general (Fernandes et al 2004b).

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Maximum limits

In May 2001, the EU Scientific Committee on Food (SCF) adopted an opinion on the Risk Assessment of Dioxins and Dioxin-like PCBs in Food based on available scientific information (SCF 2001). The SCF fixed a tolerable weekly intake (TWI) for dioxins and dioxin-like PCBs of 14 pg WHO-TEQ/kg body weight. Exposure estimates indicate that a considerable proportion of the Community population still exceeded the tolerable intake. More than 90% of human exposure is through the diet.

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The EU therefore adopted a strategy to reduce the presence of dioxins and dioxin-like PCBs in food. The strategy focussed on two aspects – current and future measures to

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reduce the release of these compounds to the environment and the setting of maximum and target levels for them in food and animal feed (Verstraete 2002, Council Regulation 2375/2001, Commission Recommendation 2002). Current measures included the setting of maximum permissible limits of PCDD/Fs in a range of foods including fish oils, whereas future measures concentrated on the target PCDD/F level reductions to be achieved in the future, as well as the inclusion of dioxin-like PCBs in the current PCDD/F maximum limits. Thus, from July 2002 limits were set for PCDD/Fs, with a view to including dioxin-like PCBs by 31 December 2004. Due to the complexity of negotiations, this is unlikely to have been achieved before the second half of 2005. Since July 2002, and subsequent to the collection of samples for this survey, the maximum permissible and target levels applying to PCDD/Fs in fish oil intended for human consumption, have been 2 ng/kg and 1.5 ng/kg WHO-TEQ, respectively.

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It is evident from the data for PCDD/Fs presented in Table 1, that 12 products contained PCDD/Fs at concentrations in excess of what was to become the limit. Of these, 11 were cod liver oils and one was a salmon oil. A further cod liver oil product exceeded the future action limit. On the other hand, approximately 64% of the products surveyed contained PCDD/F concentrations below the limit. In view of the intention, to bring dioxin-like PCBs into the Regulation, assessment is included of the dioxin-like PCB concentrations of the products surveyed. At the time of writing, the current proposal is for a total WHO-TEQ limit (dioxins plus dioxin-like PCBs) of 10 ng/kg WHO-TEQ in marine oils intended for human consumption, based on a contribution of up to 8 from dioxin-like PCBs. On this basis, 13 of the products tested would be in exceedence.

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This limit will be reviewed in 2007 with the expectation of a significant reduction, which is likely to require the introduction of new purification techniques by producers of fish oil supplements. Norway already applies a national limit of 3 ng/kg TEQ for dioxin-like PCBs, although it should be noted that consumption of fish oil, as well as fish, is particularly high in Norway. Furthermore, Norwegian oil producers already use molecular distillation techniques to reduce the PCB content. According to the data in Table 1, only 8 products contain PCB concentrations below 3 ng/kg WHO-TEQ.

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The WHO-TEQ values for cod liver oil (the majority of products – 82% of the samples) in this survey (2001-2002) ranged from 0.18 – 8.4 (mean 2.7, median 0.9) ng/kg for PCDD/Fs. This compares to a range of 1.6 – 10 (mean 5.7, median 6.7) ng/kg WHO-TEQ for cod liver oil products surveyed in 1996 (MAFF 1997). The decrease in levels indicates a trend towards lower PCDD/F levels relative to earlier surveys. This is borne out by the fact that the median exceeds the mean in the earlier survey, indicating that a greater number of samples were towards the higher end of the range of measured values. A very similar decrease in mean and median can be observed for PCBs, with the mean concentration in cod liver oil falling from 25 to 10 ng/kg Σ PCB WHO-TEQ and the median even more significantly, from 28 to 5.1 (FSA 2002). This is in line with the general downward trend for dioxins and PCBs in food in the UK (Fernandes et al. 2004b), although levels of PCBs remain higher than the corresponding levels of dioxins. The general fall may reflect either alternative sourcing of crude oils and/or the introduction or increased use of carbon filtration for the processing of fish oils, since carbon is known to remove dioxins and furans more effectively than it does PCBs. In any event, to achieve lower PCB levels in fish oil in the future, it is highly probable that producers will need to make further technological changes.

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Human Exposure

In 2001, the UK Committee on Toxicity of Chemicals in Food, Consumer Products and the Environment (COT) issued a statement (DOH 2001) on human dietary exposure to dioxins and dioxin-like PCBs, where by the UK tolerable daily intake (UK TDI) for combined dioxin and dioxin-like PCBs was revised from 10 pg/kg bodyweight/day to 2 pg/kg TEQ bodyweight/day. This value is in line with that recommended by the EU SCF for dioxins and dioxin-like PCBs of 14 pg WHO-TEQ/kg bw/week (SCF 2001) or the WHO/JECFA recommended limit of 70 pg WHO-TEQ/kg bw/month (FAO/WHO 2001).

Deleted: Thus where to some extent contaminant exclusion methodologies have had some success in reducing the dioxin component of the WHO-TEQ, the emphasis should now move to excluding PCBs as well, from these products. As crude fish oils are not used it is difficult to identify a trend in these data that might reflect a decline in environmental or marine levels of these contaminants.

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The UK Food standards Agency (FSA) has estimated a range of exposures (FSA 2002) for a wide section of the population ranging from schoolchildren to adults and the elderly, based on the data obtained from this survey, and these are summarized in Table 4. The summary distinguishes exposure from cod liver oil products and from other fish oil products, such as salmon oil. These two headings cover bottled product as well as capsules. The exposures were estimated by taking into account the suggested dosages for each of the age groups for which the products were recommended. The summary also provides estimate ranges for consumption of the products alone as well as in combination with the whole of the diet. Estimates for the dietary contribution were made from figures for mean dietary exposure as well as high level dietary exposure and were based on the 1997 Total Diet Study (FSA 2000), the most recent data available at the time.

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Insert Table 4 here

1 The ranges summarized in Table 4 show that exposure resulting from cod liver oil
 2 products was generally higher than that from other fish oil products, although it is
 3 important to bear in mind that there were only 6 products in the latter group. The data
 4 also show that the consumption of some products at the manufacturer recommended
 5 doses would result in exposures exceeding the UK TDI and would provide a higher
 6 intake of dioxins than from the whole diet (FSA 2002). The 1997 TDS provided
 7 figures for an average dietary exposure of 1.8 pg WHO-TEQ/kg bodyweight/day for
 8 adults and 2.2 pg WHO-TEQ/kg bodyweight/day for schoolchildren. Subsequent
 9 estimates by the FSA (FSA 2003) show that intakes had apparently fallen by around
 10 50% between 1997 and 2001. Products with PCDD/F and PCB concentrations leading
 11 to exposure at the upper end of the ranges given for fish oil supplements would
 12 therefore make a significant contribution to the total exposure, amounting to twice the
 13 TDI for two of the products. On the advice of the COT, the UK Food Standards
 14 Agency requested manufacturers to withdraw the affected batches of those two
 15 products (FSA 2002). Fish oil supplement producers were also advised to consider
 16 measures to further reduce dioxin and dioxin-like PCB exposure from their products,
 17 for example by differential sourcing of fish oils with lower contaminant contents,
 18 more effective purification of the oils or changes to recommended dosages and age
 19 ranges of products if they were not already doing so (FSA 2002). The Agency also
 20 reiterated the need for dosages and age recommendations to be clearly stated in order
 21 to minimize the potential for excessive intakes of dioxins and PCBs. A more recent
 22 exposure assessment resulting from fish oil consumption made in Norway
 23 (Norwegian Scientific Committee for Food Safety, 2004) reports a dioxin and dioxin-
 24 like PCB intake of 0.2 pg WHO-TEQ/kg bodyweight/week for adults and 0.9 pg
 25 WHO-TEQ/kg bodyweight/week for children. This value is based on the consumption
 26 of a popular brand of fish oil and may not reflect the variation observed in the
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1 contents of dioxin and PCBs in these products. As observed earlier, the gradually
 2 declining dioxin and PCB levels in fish or better purification techniques, (or a
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 4 combination of the two) may account for these reported exposure values.
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10 Conclusions

11 This survey of fish oil dietary supplements for dioxins/furans and dioxin-like PCBs
 12 demonstrates continued surveillance in the UK of a product that can make a
 13 significant contribution to the total human exposure to these contaminants. The data
 14 obtained for dioxins and dioxin-like PCBs are in good agreement with a
 15 contemporaneous survey of fish oils carried out by the [Food Safety Authority of](#)
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 22 [Ireland \(FSAI\)](#).
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25 The results of this survey suggest that, while some products [contain](#) lower PCDD/F
 26 [levels compared with](#) earlier surveys, [dioxin and dioxin-like PCB concentrations for a](#)
 27 [number of products in this survey would exceed a proposed EU limit of 10 ng/kg total](#)
 28 [WHO-TEQ, whilst](#) the majority of products exceed [an existing](#) Norwegian limit of 3
 29 ng/kg WHO-TEQ [for dioxin-like PCBs](#). [Since a future review is likely to drive limits](#)
 30 [down towards the values applied by Norway](#), fish oil purification processes [will](#)
 31 [probably need to be modified to achieve a significant](#) reduction of PCB levels.
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42 Estimates of human exposure to different population groups resulting from
 43 consumption of the fish oil products [alone](#), as well as in combination with an average
 44 diet, show that some products would give exposures in excess of the TDI.
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 48 [Consequently](#), the UK FSA recommended that the relevant manufacturers withdraw
 49 affected batches of the products from sale.
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2 The toxicological significance of the exposure data for these products needs to be
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4 balanced with the many beneficial effects that they are reported to have on human
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6 health. It is desirable to continue to benefit from these products, whilst reducing
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8 exposure to contaminants. It is therefore recommended that surveillance of these
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10 products for PCBs and dioxins should continue.

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Table 1: Concentrations of dioxins and PCBs (upper bound) in individual fish oil products. (n=33)

Deleted: Individual concentrations

Deleted: ΣWHO-TEQ

Sample No	Σ PCDD/F WHO-TEQ	Σ non-ortho PCB WHO-TEQ	Σ o-PCB WHO-TEQ	Σ Total WHO-TEQ	Σ o-PCBs & non-ortho PCB WHO-TEQ	Σ ICES 7 PCBs
	ng/kg fat	ng/kg fat	ng/kg fat	ng/kg fat	ng/kg fat	µg/kg fat
5897	4.84	7.73	2.06	14.6	9.79	73.1
5898	4.58	10.3	3.11	18.0	13.4	115
5899	1.52	9.17	2.18	12.9	11.4	53.2
5900	2.54	7.58	2.07	12.2	9.65	53.1
5901	4.55	31.3	10.1	46.0	41.5	267
5902	0.38	1.17	1.69	3.24	2.86	81.2
5903	0.85	0.56	2.93	4.34	3.49	115
5908	0.23	2.48	0.53	3.24	3.01	22.6
5909	0.86	0.82	0.3	1.98	1.12	8.3
5910	5.9	20.3	7.4	33.6	27.7	224
5911	5.29	17.1	4.91	27.3	22.0	146
6465	6.47	10.0	3.24	19.7	13.3	124
6466	0.87	0.98	3.81	5.66	4.79	177
6467	0.49	1.92	0.33	2.74	2.25	12.0
6468	0.77	1.72	0.41	2.9	2.13	14.6
6469	5.11	8.33	2.8	16.2	11.1	101
6470	3.92	9.82	3.1	16.8	12.9	93.9
6471	0.61	1.25	1.86	3.72	3.11	65.5
6472	0.93	2.68	2.39	6.0	5.07	81.9
6473	0.5	1.24	1.89	3.63	3.13	65.6
6474	0.73	2.24	2.93	5.9	5.17	107
6475	0.53	1.65	2.81	4.99	4.46	103
6476	0.57	2.15	2.95	5.67	5.1	107
6477	0.7	0.62	1.8	3.12	2.42	87.7
6478	0.73	1.06	1.86	3.65	2.92	89.3
6479	0.18	0.67	2.37	3.22	3.04	98.4
6480	6.34	14.2	4.62	25.1	18.8	153
6481	8.4	18.5	6.04	33.0	24.6	196
6710	7.87	19.1	5.83	32.8	24.9	196
6711*	0.32	0.17	0.28	0.77	0.45	7.4
6712	0.22	0.78	1.03	2.03	1.81	43.8
6731	1.33	3.17	0.83	5.33	4.0	30.8
6995	0.31	0.58	0.96	1.85	1.54	39.5

* Unspecified fish oil content, data presented on a whole weight basis. This datapoint is generally not included in discussion.

Table 2: Summary of concentration data with descriptive statistics

Parameter	Σ PCDD/F	Σ non-ortho PCBs	Σ o-PCBs	Σ WHO-TEQ	Σ ICES 7 PCBs
N=32*					
ng/kg fat weight					
Mean	2.5	6.6	2.8	11.9	98.3
Median	0.9	2.4	2.4	5.7	91.6
Skewness	1.0	1.5	1.6	1.3	0.8
Minimum	0.2	0.6	0.3	1.9	8.3
25th Percentile	0.6	1.1	1.8	3.2	53.2
50th Percentile	0.9	2.4	2.4	5.7	91.6
75th percentile	4.6	9.9	3.1	17.1	117.5
Maximum	8.4	31.3	10.1	46.0	266.6
SD	2.6	7.7	2.2	11.8	63.0
Mean+2sd	7.6	21.9	7.2	35.6	224.4
% contribution to ΣWHO-TEQ	21	55	24		

* One sample not included due to unspecified fish oil content.

Skewness – extent of asymmetry of a distribution relative to the mean

Table 3: Comparison with recent literature data (FSAI, 2002).

Parameter	Σ PCDD/F TEQ		Σ o-PCB & non-ortho PCB TEQ		Σ WHO-TEQ	
	UK	Ireland	UK	Ireland	UK	Ireland
UK, n=32						
Ireland, n=15						
Mean	2.5	3.6	9.4	13.4	11.9	17.0
Median	0.9	3.1	4.8	14.0	5.7	17.9
Skewness	1.0	1.0	1.7	0.2	1.3	0.2
Minimum	0.2	0.2	1.1	0.2	1.9	0.6
Maximum	8.4	11.0	41.5	29.8	46.0	37.6
SD	2.6	3.1	9.6	8.3	11.8	10.9
Mean+2sd	7.6	9.7	28.7	30.0	35.6	38.7
% contribution to Σ WHO-TEQ	21	21	79	79		

Table 4: Human exposure arising from fish oil supplement consumption.

Exposure in pg WHO-TEQ/kg bodyweight/day		
Population group	Cod liver oil products	Other fish oil products
<i>Fish oil supplements only</i>		
Children, 4-18 yrs	0.02 to 10	0.04 to 4.9
Adults	0.02 to 7.1	0.04 to 1.7
Elderly	0.01 to 6.9	0.03 to 1.6
<i>Fish oil supplements + average diet in 1997</i>		
Children, 4-18 yrs	1.4 to 14	1.4 to 8.1
Adults	1.8 to 8.9	1.8 to 3.5
Elderly	1.3 to 8.6	1.3 to 3.3
<i>Fish oil supplements + high level diet in 1997</i>		
Children, 4-18 yrs	2.5 to 16	2.5 to 11
Adults	3.1 to 10	3.1 to 4.8
Elderly	2.3 to 9.8	2.3 to 4.5

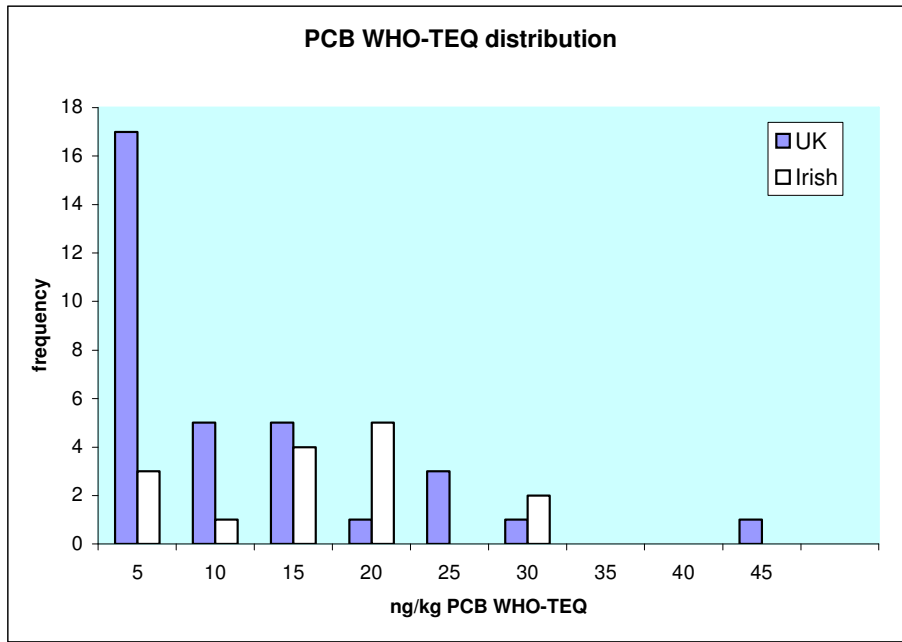


Figure 1. Data distribution for UK and Irish studies