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Dietary arsenic intakes in the United States: FDA Total Diet Study, September 1991–December 1996

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The FDA has conducted the Total Dietary Study (TDS), a yearly market basket programme, since 1961. It is designed to monitor the levels of toxic chemical contaminants (pesticide residues, industrial and elemental contaminants) and essential nutrients in the US food supply. It also provides information on trends in dietary concentrations and exposures for the general population. Foods are collected from retail stores once a year from each of four geographic areas of the US and are analysed either after preparation/cooking or as ready-to-eat. The latest TDS (1991–1997) data show that arsenic (inorganic and organic, ⩾ 0.03 ppm) was found in 63 (24%) of the 261–264 foods/mixed dishes analysed. The highest concentration was found in seafood, followed by rice/rice cereal, mushrooms, and poultry. Based on the United States Department of Agriculture's 1987–1988 Nationwide Food Consumption Survey, the estimated daily total arsenic average intakes, in μg/day, are: 2 for infants, 23 for toddlers, 20 for 6-year-old children, 13 for 10-year-old children, 15 for 14–16-year-old boys, 21 for 14–16-year-old girls, 57 for 25–30-year-old men, 28 for 25–30-year-old women, 47 for 40–45-year-old men, 37 for 40–45-year-old women, 92 for 60–65-year-old men, 72 for 60–65-year-old women, 69 for 70-year-old men, and 42 for 70-year-old women. Of the estimated total arsenic intakes for infants, 42% arise from seafood and 31% from rice/rice cereals. Of the estimated total arsenic intakes, seafood contributes 76–90% for children (2–10-year olds), 79–85% for 14–16-year olds, and 89–96% for adults (⩾ 25–30-year olds); rice/rice cereals contributes 4–8% for children, 8% for 14–16-year olds, and 1–4% for adults (⩾ 25–30-year olds).

Keywords: arsenic, dietary intakes, total diet study, USA

Introduction

Arsenic is widely distributed in the environment from both natural and anthropogenic sources. The major route of human exposure to arsenic is via ingestion. For the general population of non-smokers with no exposure to arsenic through their occupation or an arsenic-polluted environment, diet is the largest source of exposure in the United States. Arsenic intakes from drinking water are much less than that from food. Arsenic concentration in the US drinking water is typically a few micrograms per litre (ATSDR 1991).

The United States Food and Drug Administration (FDA) has conducted the annual Total Dietary Study (TDS), also known as the Market Basket Study, since 1961. The purpose of the TDS is to monitor the safety and the nutritional quality of the US food supply. It provides both baseline information on the levels of radionuclides, pesticide residues, industrial and elemental contaminants, and nutrients in foods and on the estimated intakes of these substances in the daily diets of various age–sex groups. It also identifies the trends and changes, both in concentrations and exposures, of these substances in the food supply and diets of the general population over time. Arsenic is one of the contaminants that has been analysed in the TDS since the beginning of the programme. Since May 1982, TDS foods have been analysed individually (Pennington 1983) instead of as composites to provide greater flexibility of estimating intake distributions of food contaminants in various population groups. Intakes of arsenic are calculated based upon representative national food consumption data and

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the analytical total arsenic concentration data in individual foods.

This paper presents the results of arsenic in the Total Diet Study on food samples collected during the period from September 1991 to December 1996. Results for prior periods from 1982 to 1991 have been reported previously (Gunderson 1988, 1995a, b, Adams *et al.* 1994). The estimated intakes are those representing average consumers.

Methods

In the TDS, a shopping list of foods and diets is generated from a small number of core foods (Pennington 1992c). These foods represent the most commonly consumed foods in the United States as determined by changes in the food supply and consumption patterns. A total of 264 foods was purchased three to four times a year by FDA inspectors. Foods were purchased from retail stores in designated cities from each of four geographical regions and analysed in an FDA TDS laboratory. For each collection or market basket, identical food items were purchased from three cities, prepared and cooked as those at home or as ready for consumption. Samples of each food item collected from the designated cities were then combined for analysis. Total arsenic, i.e. inorganic and organic forms combined, in food was determined by hydride generation atomic absorption spectrometry. Details of analytical methodology and quality assurance practices were cited and described previously (Capar 1991, Pennington and Gunderson 1987, Pennington *et al.* 1996).

Arsenic intakes are estimated from analysis of the core foods that make up the Total Diets for various age–sex groups and the quantities of these foods consumed. Quantities of these foods are determined based upon food consumption data from the 1987–1988 US Department of Agriculture's (USDA) National Food Consumption Survey (NFCS). Arsenic concentrations from the analysis results are multiplied by the quantity of each food consumed to give an estimate of average dietary intake of total arsenic in each specified population group. Compared with the previous revision (Pennington 1983), the most recent revision of TDS (Pennington 1992a, b) has expanded to include 14 age–sex groups and up to 264 core foods.

Table 1. Major food groups and typical adult daily intakes, US FDA Total Diet Study (1990 revision)[a].

Food group	TDS foods *n*	Mean food intake (g/day)[b] Men		Women	
A. Milk and cheese	12	257	(9.1%)	201	(8.3%)
B. Eggs	3	28	(1.0%)	18	(0.7%)
C. Meat, poultry and fish	24	146	(5.2%)	94	(3.9%)
D. Legumes and nuts	7	31	(1.1%)	12	(0.5%)
E. Grain products	28	140	(5.0%)	104	(4.2%)
F. Fruits	27	126	(4.5%)	114	(4.7%)
G. Vegetables	40	186	(6.6%)	137	(5.6%)
H. Mixed dishes and meals	28	202	(7.1%)	157	(6.4%)
I. Desserts	21	62	(2.2%)	49	(2.0%)
J. Snacks	4	13	(0.5%)	7	(0.3%)
K. Condiments and sweeteners	10	19	(0.7%)	13	(0.5%)
L. Fats and dressings	11	26	(0.9%)	20	(0.8%)
M. Beverages	14	1588	(56.2%)	1511	(62.0%)
N. Infant and junior foods	35[c]	0		0	
Total	264[c]	2825	(100.1%)	2437	(99.9%)

[a] A complete food list is published (Pennington 1992c).
[b] For 25–30-year-old adults.
[c] After October 1992, three food items were dropped because of non-availability.

Table 2. TDS foods frequently found with arsenic concentrations equal to or above 0.03 ppm (FDA TDS 1991–1997, 18 market baskets).

TDS food description	Baskets (*n*)	Range (As, μg/g)
Seafood		
Tuna, canned in oil	18/18	0.609–1.470
Fish sticks, commercial	18/18	0.380–2.792
Haddock, pan-cooked	18/18	0.510–10.430
Shrimp, boiled	18/18	0.290–2.681
Grain products		
Rice, white, cooked	18/18	0.030–0.110
Crisped rice cereal	18/18	0.070–0.304
Granola, with raisins	8/18	0.030–0.050
Vegetables		
Mushrooms, raw	16/18	0.034–0.203
Poultry		
Chicken, drumsticks and breasts, homemade	8/18	0.030–0.086
Chicken breast, roasted	7/18	0.031–0.083
Chicken, fried (breast, leg, thigh), fast-food	7/18	0.031–0.083
Mixed dishes and meals		
Tuna noodle casserole	17/18	0.050–0.244
Fish sandwich on bun, fast-food	18/18	0.133–1.600
Clam chowder, New England, canned	17/18	0.080–0.206
Infant and junior foods		
Rice infant cereal, instant, with whole milk	15/18	0.032–0.087

Table 3. Estimated average inorganic arsenic intakes for various age–sex groups (FDA TDS 1991–1997, 18 market baskets).

Age–sex group		Total As intake (μg/day)	Inorganic As intake[b] (μg/day)		Total inorganic As average intake	
Age	Weight[a] (kg)		Seafood	Others	μg/day	%PTDI[c]
6–11 months	7	2.15	0.09	1.25	1.34	8.9
2 years	13	23.4	2.11	2.30	4.41	15.8
6 years	22	20.3	1.74	2.90	4.64	9.8
10 years	64	13.3	1.01	3.20	4.21	3.1
14–16 years F	53	21.8	1.85	3.30	5.15	4.5
14–16 years M	64	15.4	1.21	3.30	4.51	3.3
25–30 years F	62	27.5	2.46	2.90	5.36	4.0
25–30 years M	79	56.6	5.19	4.70	9.89	5.8
40–45 years F	67	36.8	3.38	3.00	6.38	4.4
40–45 years M	81	46.8	4.28	4.00	8.28	4.8
60–65 years F	67	72.1	6.93	2.80	9.73	6.8
60–65 years M	81	92.1	8.84	3.70	12.54	7.2
70+ F	62	45.4	4.25	2.90	7.15	5.4
70+ M	74	69.4	6.63	3.10	9.70	6.1

[a] Self-reported weights from the USDA data tapes.
[b] Based on the assumption that 10 and 100% of the total arsenic is inorganic arsenic in seafood and all other foods, respectively. Seafood includes seven TDS food items (tuna, fish sticks, haddock, shrimp, tuna noodle casserole, clam chowder, and fish sandwich).
[c] WHO's provisional tolerable daily intake (PTDI) of 2.1 μg/kg body weight per day for inorganic arsenic, derived from the PTWI of 15 μg/kg body weight per week.

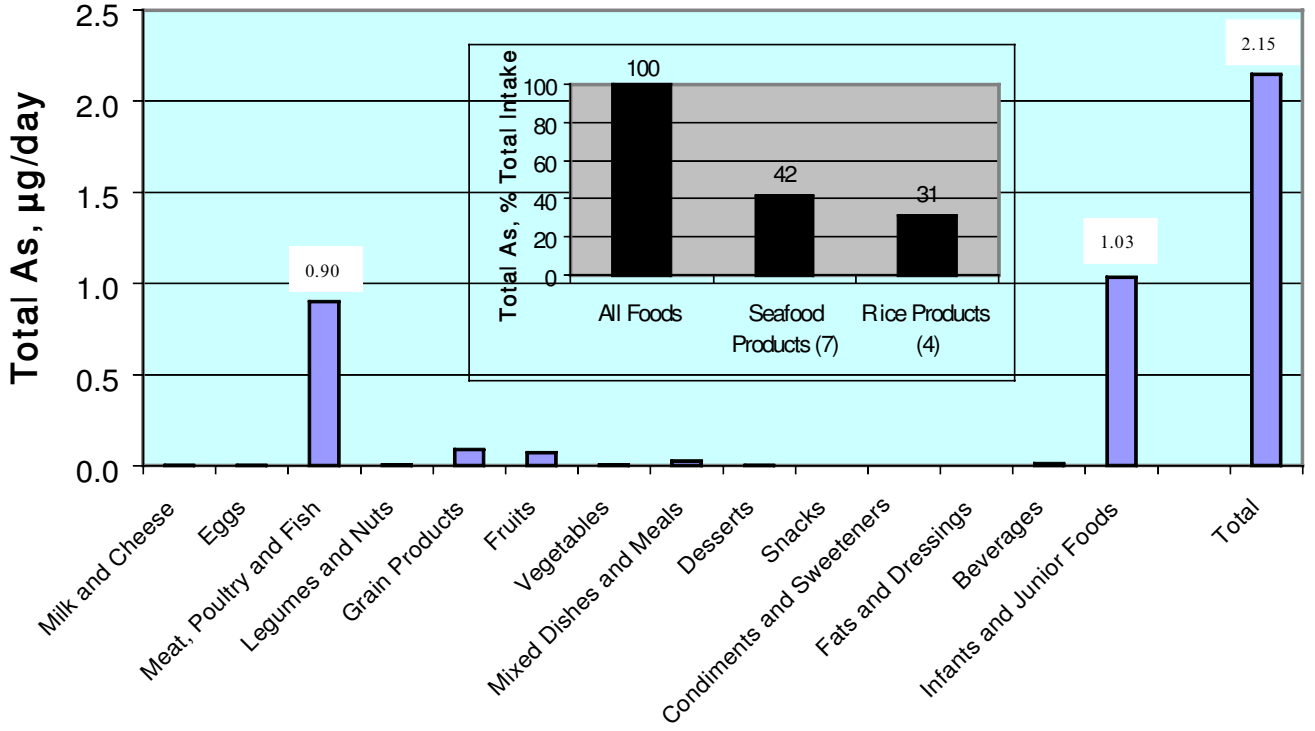

Figure 1. Total arsenic intake by food group for 6–11-month-old infants, 1991–1997 (18 baskets).

Insert: Seafood products (7 TDS foods)—tuna, fish sticks, haddock, shrimp, tuna noodle casserole, clam chowder, and fish sandwich. Rice products (4 TDS foods)—rice, crisped rice cereal, instant rice infant cereal, and strained/junior rice cereal.

Results and discussion

Table 1 lists the number of TDS foods in each of the 14 major food groups. A complete food list was published previously (Pennington 1992c). The current study covers the period from September 1991 to December 1996 and includes a total of 18 market baskets, consisting of 261–264 individual foods or mixed dishes that were collected and analysed for arsenic. Typically total arsenic concentrations in TDS foods were low, less than 0.03 ppm. Out of 261–264 TDS foods, only 63, or 24%, contained arsenic at 0.03 ppm or above in any one or more baskets. In addition, only 15, or 6%, TDS foods had 0.03 mg/kg or higher total arsenic (table 2) in at least one-third of the 18 baskets. Seafood contained the highest levels of total arsenic, followed by rice and/or rice cereal, mushroom, and poultry. Other than seafood, few TDS foods contained total arsenic levels greater than 0.08 ppm. The concentration of arsenic in tap water was below the detection limit (0.01 ppm for samples collected during 1991–1993, 0.002 ppm for samples collected later than 1993) in all 18 baskets.

Table 3 shows the estimated typical or average daily intakes of total arsenic for the 14 age–sex groups. They ranged from 2 µg/day in infants to 92 µg/day in 60–65-year-old men. Except for toddlers, whose intakes approach the WHO's provisional tolerable weekly intake (PTWI) for inorganic arsenic of 0.015 mg/kg body weight (equivalent to 2.1 µg/kg body weight/day) (WHO 1989), all other age–sex groups have intakes well below their respective PTWI values for inorganic arsenic. The PTWI is an estimate, based upon current scientific evidence, of the amount of a substance that can be ingested over a lifetime without considerable risk of non-carcinogenic adverse effects. The average total arsenic intakes of US adults (25–30-year-olds) were 56.6 and 27.5 µg/day for men and women, respectively (table 3). The difference in arsenic intakes between

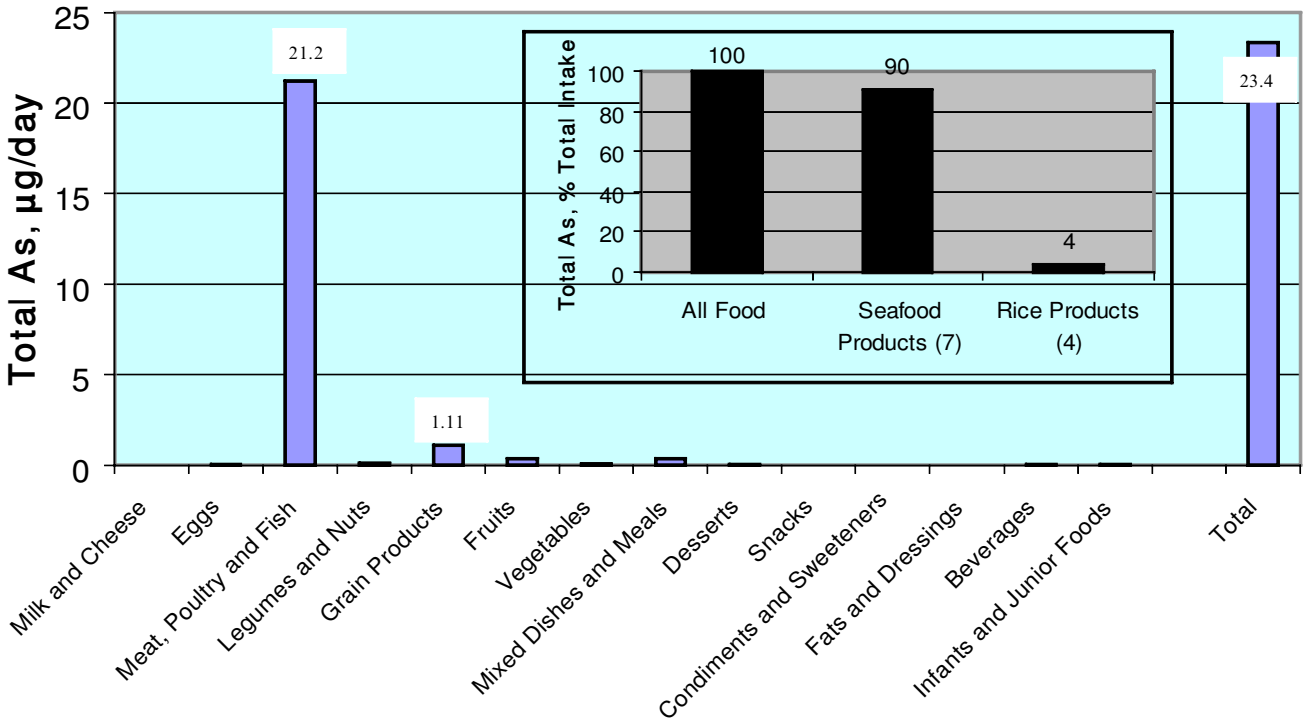

Figure 2. Total arsenic intake by food group for 2-year-old children, 1991–1997 (18 baskets).

Insert: Seafood products (7 TDS foods)—tuna, fish sticks, haddock, shrimp, tuna noodle casserole, clam chowder, and fish sandwich. Rice products (4 TDS foods)—rice, crisped rice cereal, instant rice infant cereal, and strained/junior rice cereal.

men and women was mainly due to higher consumption of food, particularly seafood, in men (table 1).

The average dietary intake of total arsenic for adult males (25–30-years-old) in this study is similar to and higher than that previously reported for the period of 1984–1986 and 1986–1991, respectively (Gunderson 1995a, b). In comparison, the estimated dietary arsenic intakes are lower in Belgium: 12 µg/day (Buchet *et al.* 1983), Croatia: 11.7 µg/day (Sapunar-Postruznik *et al.* 1996), Canada: 16.7 µg/day (Dabeka *et al.* 1987), the Netherlands: 15 µg/day (de Vos *et al.* 1984) and 38 µg/day (van Dokkum *et al.* 1989), similar in Canada: 59.2 µg/day (Dabeka *et al.* 1993), Sweden: 60 µg/day (Jorhem *et al.* 1998), the UK: 56–67 µg/day (MAFF 1998) and 63 µg/day (MAFF 1997), and higher in Denmark: 118 µg/day (NFAD 1997), Japan: 160–280 µg/day (Tsuda *et al.* 1995).

Although intakes of seafood and its products represent only a small portion (< 1.5%) of a typical diet, the daily total arsenic intakes were in proportion to the amounts of seafood and seafood products consumed. Total arsenic intakes contributed by each food group were estimated for all 14 age–sex groups. The results for infants, 2-year-old children, 14–16-year-old boys and 25–30-year-old men are shown in figures 1–4, respectively. The greatest dietary contribution of total arsenic intakes (76–96%) came from seafood for 2-year-olds and older. Seafood and rice/rice cereals contributed 42 and 31%, respectively, of the total arsenic intake of infants (figure 1 insert).

Seafood arsenic is mostly (80–99%) present in organic, the non-toxic forms (ATSDR 1993, Edmonds and Francesconi 1993, Larsen *et al.* 1993, Buchet *et al.* 1994). Data on chemical forms of arsenic in foods other than seafood are lacking. Yost *et al.* (1998) reported, with limited preliminary data, total arsenic in various food groups and broken down by the percent inorganic to total arsenic. Of the total arsenic, inorganic arsenic represents 43% in rice, 49% in

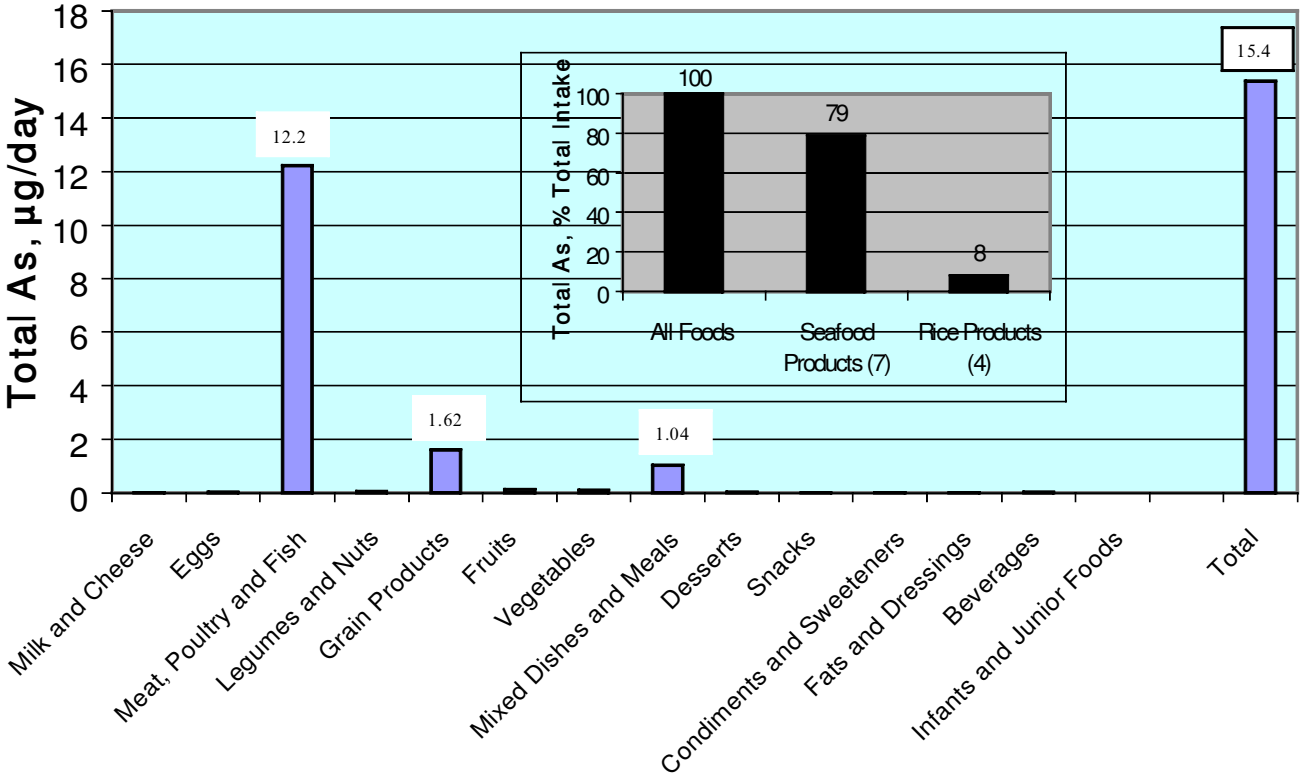

Figure 3. Total arsenic intake by food group for 14–16-year-old boys, 1991–1997 (18 baskets).

Insert: Seafood products (7 TDS foods)—tuna, fish sticks, haddock, shrimp, tuna noodle casserole, clam chowder, and fish sandwich. Rice products (4 TDS foods)—rice, crisped rice cereal, instant rice infant cereal, and strained/junior rice cereal.

cereals, and 1% in marine fish. Based on a conservative assumption that 10% of the total arsenic in seafood and 100% of the total arsenic in all other foods are inorganic, the estimated inorganic arsenic intakes would vary from 1.3 µg/day (9.4 µg/week) in infants to 12.5 µg/day (87.8 µg/week) in 60–65-year-old men (table 3). These estimated inorganic arsenic intakes amount to only 3–16% of their respective PTWI values. Even for extreme consumers of seafood, who may have arsenic intakes two to three times that of the average consumers, their intakes of inorganic arsenic would still be below the PTWI and would not represent any health risk. Therefore, it is clear that the national US diet contributes very small amounts of inorganic arsenic, which is of little health concern. Potential health risks of inorganic arsenic may exist in populations who are exposed to elevated arsenic from other sources such as in drinking water and in the workplace.

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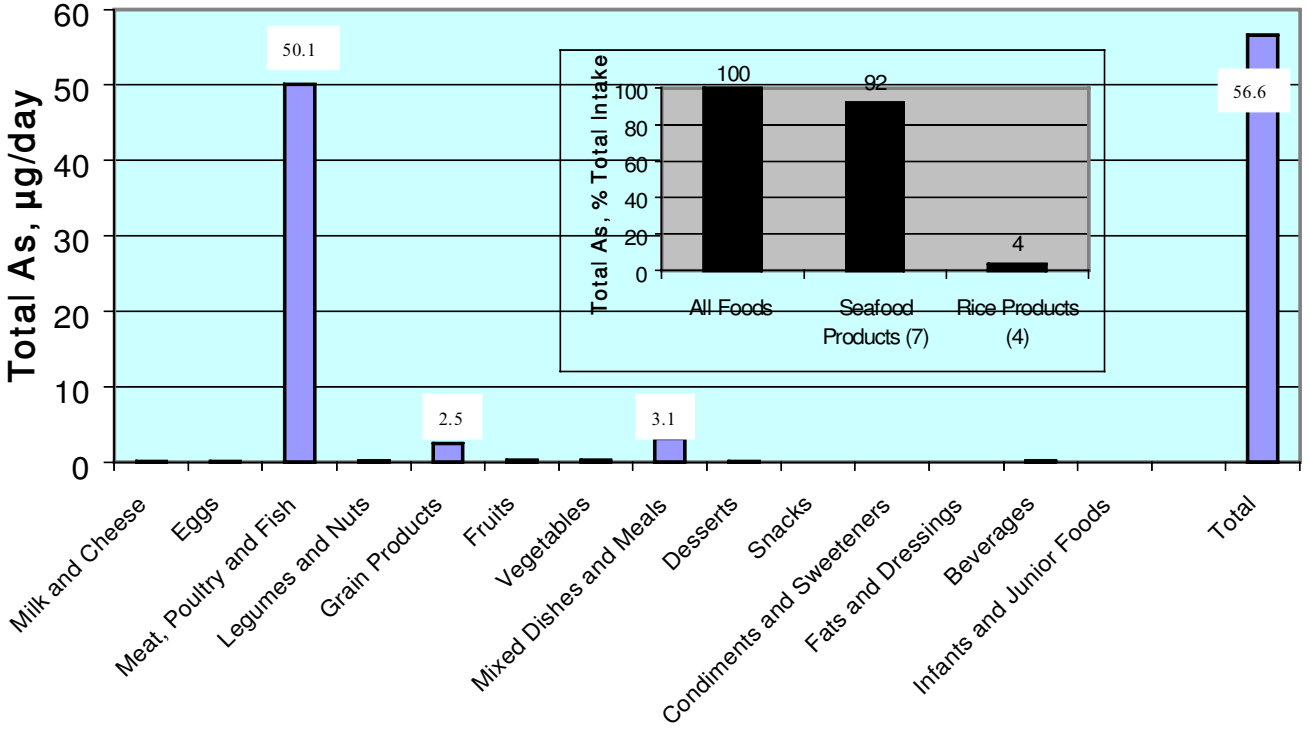

Figure 4. Total arsenic intake by food group for 25–30-year-old men, 1991–1997 (18 baskets).

Insert: Seafood products (7 TDS foods)—tuna, fish sticks, haddock, shrimp, tuna noodle casserole, clam chowder, and fish sandwich. Rice products (4 TDS foods)—rice, crisped rice cereal, instant rice infant cereal, and strained/junior rice cereal.

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