Zinc Intake of the U.S. Population: Findings from the Third National Health and Nutrition Examination Survey, 1988–1994[1]

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ABSTRACT National survey data for 29,103 examinees in the third National Health and Nutrition Examination Survey were used to estimate mean and percentile distributions of dietary and total zinc intakes based on 24-h dietary recalls and vitamin/supplement use. Mean daily total intakes ranged from 5.5 mg in non–breast-feeding infants to 13 mg in adults and were higher in adolescent and adult males than in females ($P < 0.01$). Mean total zinc intakes (22 mg) were ~10 mg higher in pregnant and lactating females than in nonpregnant, nonlactating females of the same age. Mean total zinc intakes were 0.7 mg higher in adolescents (11.1 mg) and 2.5–3.5 mg higher in adults (13 mg) compared with mean dietary intakes, indicating the average contribution of supplements to total zinc intake. Mean total zinc intakes were significantly higher in non-Hispanic whites than in non-Hispanic blacks ($P < 0.01$) and Mexican Americans ($P < 0.01$) for men and women aged 51–70 y and ≥71 y due to higher zinc supplement use. The prevalence of zinc-containing supplements use ranged from 0.1% in infants to 20.5% in adults. "Adequate" zinc intake in this survey population was 55.6% based on total intakes of >77% of the 1989 recommended dietary allowance. Young children aged 1–3 y, adolescent females aged 12–19 y and persons aged ≥71 y were at the greatest risk of inadequate zinc intakes. J. Nutr. 130: 1367S–1373S, 2000.

KEY WORDS: • *zinc intake* • *diet* • *supplements* • *National Health and Nutrition Examination Survey (NHANES)* • *recommended dietary allowance (RDA)*

The Centers for Disease Control and Prevention's National Center for Health Statistics (NCHS)[3] conducts the periodic National Health and Nutrition Examination Surveys (NHANES) to assess the health and nutritional status of the U.S. civilian, noninstitutionalized population. The most recent survey, the third National Health and Nutrition Examination Survey (NHANES III), was conducted in 1988–1994 on a cross-sectional sample representative of the U.S. population aged ≥2 mo (NCHS 1994). The NHANES is unique in that information is collected on dietary intake, vitamin and mineral supplement use, nutritional biochemistries and health parameters in the same individuals. The NHANES III is the first national survey to estimate total nutrient intake using food and beverage intake data from 24-h dietary recalls and detailed information on dietary supplement use.

There are a number of health-related reasons for evaluating the range of zinc consumption from diet and supplements in the U.S. population and across subgroups. Signs and symptoms of dietary zinc deficiency include loss of appetite, growth retardation and sexual immaturity, skin changes, diarrhea, loss of appetite, hair loss and immunologic abnormalities (Cousins 1996, National Research Council 1989, Wada and King 1994). Zinc deficiency may arise from low dietary intakes, low bioavailability and/or interaction with other nutrients and losses of the mineral through disease processes (Cousins 1996, Wada and King 1994, Walsh et al. 1994). Older individuals appear to be at particular risk for zinc deficiency because of poor appetite, difficulties in chewing, interaction with medications and changing nutrient requirements associated with changes in physiology and metabolism with aging (Bales et al. 1994, Wood et al. 1995).

Zinc toxicity due to acute or chronic ingestion of high quantities of zinc supplements can also occur and lead to impaired immune response, hypocupremia, microcytosis, neutropenia, inhibition of copper and iron absorption, respiratory and gastrointestinal toxicity, inhibition of neurological devel-

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[3] Abbbreviations used: NCHS, National Center for Health Statistics; NHANES, National Health and Nutrition Examination Survey; RfD, reference dose; RDA, recommended dietary allowance.

opment and a decline in HDL levels (Abdel-Mageed and Oehme 1990, Cousins 1996, National Research Council 1989, Walsh et al. 1994, Wood et al. 1995). The effects of moderately elevated zinc intakes are difficult to assess and require biochemical and metabolic indicators to fully evaluate the zinc status of the U.S. population; these indicators may include measurements of plasma, leukocyte, hair, bone and saliva zinc levels and metabolic markers such as enzyme activity. Serum zinc was assessed in the 1976–1980 NHANES (Federation of American Societies for Experimental Biology 1984) but not included in NHANES III due to the lack of usefulness as a laboratory indicator for zinc status (Federation of American Societies for Experimental Biology 1985). Limitations of laboratory indicators are well documented and raise serious questions about their use in the evaluation of zinc status (Bales et al. 1994, Cousins 1996, Hunt 1996, Sandstead and Smith 1996, Wada and King 1994, Walsh et al. 1994).

The diagnosis of deficiency currently requires clinical signs of deficiency and information on dietary intake and supplement usage (Sandstead and Smith, 1996, Walsh et al. 1994). Intake data alone are insufficient to evaluate nutritional status, but estimates of intakes in the population can be evaluated with respect to estimates of nutrient requirements (National Research Council 1989, Gibson and Ferguson 1998). In this study, current estimates of dietary and total zinc intake collected in NHANES III are used to assess zinc intake in the U.S. population and to indicate population groups for whom zinc status may be a concern. Survey research data needs in the area of zinc and health are also identified.

MATERIALS AND METHODS

Sample population and definitions. NHANES III was designed to collect information on the U.S. population aged ≥2 mo. Children aged <6 y, persons aged ≥60 y and blacks and Mexican Americans were oversampled to produce more precise estimates for these population groups. Detailed descriptions of the plan and operation of the survey have been described elsewhere (NCHS 1994, 1996).

Data were collected through household interviews, direct standardized physical examinations and private interviews conducted in mobile examination centers ~2–4 wk after the household interview. Age determination was self-reported and made at the time of the household interview. A household interview was administered to a proxy respondent, such as the child's parent or guardian, for children aged 2 mo to 16 y. Race and ethnic categories were based on self-reported data and were combined to create the race/ethnicity groups: non-Hispanic white, non-Hispanic black, Mexican American and "other" race/ethnicity. The total population figures include data for race/ethnicity groups not shown separately.

Pregnancy status was based on self-reported information or a positive urine test (NCHS 1996). There were 341 pregnant females (age range, 14–55 y) and 99 lactating females (age range, 14–41 y) with complete 24-h recall and supplement use data. Five lactating females were also pregnant but are classified in this study as lactating because zinc requirements are higher for lactation than for pregnancy. During the examination, questions on current lactation practices were asked for women whose pregnancies ended in the past 2 y; however, the duration of lactation was not collected. Because in 1988 <25% of U.S. women breast-fed in the past 6 mo (NCHS 1997), all lactating women were evaluated using the recommended dietary allowance (RDA) for zinc for the first 6 mo of lactation (National Research Council 1989).

Estimation of dietary intakes. The 24-h dietary recalls were collected in the examination centers by trained interviewers who were bilingual in English and Spanish and used an automated NHANES III Dietary Data Collection System that has been described in detail elsewhere (McDowell et al. 1990, NCHS 1994, 1996). There were no imputations for missing 24-h recall data. In NHANES III, complete and reliable information on dietary intake and vitamin/mineral supplement use was available for 29,105 persons. Infants and children who were breastfeeding were excluded because it was not possible to compute total daily nutrient intake. Two individuals with complete and reliable 24-h recall were excluded from the study because they reported no food intake on the 24-h recall and it was not possible to log-transform a zero intake for statistical analysis. Thus, the final analytic sample size was 29,103 individuals aged ≥2 mo.

Intakes from food and beverages are referred to as dietary zinc intakes. Dietary intake estimates for the population were assessed using a single 24-h dietary recall per person and a second independent 24-h recall on a subsample ($n = 1623$) of the examined sample. Food composition data for the dietary zinc intakes were based on the U.S. Department of Agriculture Survey Nutrient Database (U.S. Department of Agriculture 1993). Because of day-to-day variation in dietary intake, estimates from one 24-h recall contain considerable within-person variation. The estimates presented here were adjusted for this within-person variation according to the method described in the National Research Council 1986 report *Nutrient Adequacy: Assessment Using Food Consumption Surveys*. The model, which was developed by Feinleib et al. (1993), is based on an assumption of normality:

$$x' = \mu + (x - \mu)*\left(\frac{\mathrm{SD}_{\mathrm{between}}}{\mathrm{SD}_{\mathrm{total\ observed}}}\right)$$

The ratio of within-person variability to between-person variability was estimated using the formula:

$$\frac{s_w^2}{s_b^2} = \frac{1 - r}{r}$$

where r is the correlation coefficient between the intake from the first and the second recall; s_w^2 is the within-person variance and s_b^2 is the between-person variance. This formula can be used to estimate the ratio as follows:

$$\frac{\mathrm{SD}_{\mathrm{total\ observed}}}{\mathrm{SD}_{\mathrm{between}}} = \frac{1}{\sqrt{1 + \left(\frac{1 - r}{r}\right)}}$$

where $\mathrm{SD}_{\mathrm{between}}$ is the between-person standard deviation and $\mathrm{SD}_{\mathrm{total\ observed}}$ is the total observed standard deviation (Sempos et al. 1991).

A subsample of the examined sample was selected, and they completed a second 24-h dietary recall. No statistical sampling design was applied, but a nonrandom sample of ~5% was obtained by selecting 20 participants from the ~400 who were examined at each survey location. There were slightly more women than men examined in the subsample and fewer children, adolescent and teens than adults. Data from the second recalls were used to estimate the ratio of between-person standard deviation to the total observed standard deviation. Weighted, age-specific mean values were used in the model. Because of the skewness of the distribution of zinc intakes, the data were log-transformed to approximate normality before the adjustment was applied. The data were transformed back to the original scale, by taking exponentials, after the adjustment.

Estimation of supplement use and total intakes. During the household interview, trained bilingual interviewers asked the survey participant or his or her proxy about their use of vitamin/mineral supplements, the brand names of the products, if known, and the frequency and amount used in the past month. The interviewer recorded the brand name, manufacturer and distributor from the supplement labels, if available. A database was compiled containing the supplements reported and their nutrient contents; this is described in detail elsewhere (NCHS 1998). Persons with missing or unknown dietary supplement use ($n = 44$, or 0.2% of the dietary sample) were assigned a value of zero for their zinc contribution from supplements for this particular analysis.

A total of 498 products in the NHANES III supplements database contained zinc. Most were single-nutrient mineral or multivitamin/mineral combinations. The zinc content for a single dosage ranged from 15 to 100 mg for single-nutrient supplements and from 2 to 50 mg (most frequently, 15–25 mg) for vitamin/mineral combination products. The contribution of zinc from supplements was calculated for each person for all products the person reported during the past month. For each product reported, the zinc content in a single dose was multiplied by the reported dose and frequency per day. Intake was then summed over all products reported. Total zinc intakes were calculated by summing estimates of the adjusted daily zinc intake from foods and beverages with the daily zinc intake from supplements.

Estimation of "adequacy" of total zinc intake. Approximations for mean nutrient requirements were based on assumptions that the 1989 RDA approximates the mean requirement plus 2 SDs with a coefficient of variation (CV) of 15% (Anderson et al. 1982, Federation of American Societies for Experimental Biology 1995, National Research Council 1986, 1989). Mean zinc requirements were then calculated as 77% of the RDA (Federation of American Societies for Experimental Biology 1995). Total zinc intakes were compared with 77% of the age- and sex-specific 1989 RDA value for zinc to determine "adequate" intakes for the population and specific population groups. The 1989 RDAs (and 77% cut points) used were: 5 mg (3.8 mg) for infants, 10 mg (7.7 mg) for ages 1–10 y; 12 mg (9.2 mg) for nonpregnant and nonlactating females aged ≥11 y, 15 mg (11.6 mg) for males aged ≥11 y and pregnant females and 19 mg (14.6 mg) for lactating females in the first 6 mo of lactation (National Research Council 1989).

Statistical methods. All mean, percentile estimates, and SE values were generated using SAS (SAS/STAT Version 6.09 Enhanced; SAS Institute, Cary, NC) and SUDAAN release 7.00 (Shah et al. 1996), a statistical program that takes into account the sampling weights and the complex sample design of the survey. Overall survey response rates were 86% for the household interview and 78% for the examination (U.S. Department of Health and Human Services 1996). More than 95% of those examined had a complete and reliable 24-h dietary recall. The sample weights are adjusted for nonresponse, based on the probabilities of selection, and poststratified to the U.S. Bureau of Census 1990 estimates of the total U.S. population. Where multiple comparisons were made, the α level was adjusted using the Bonferroni method by dividing 0.05 by the number of implied comparisons (Neter et al. 1985).

RESULTS

Mean and median dietary and total zinc intakes are shown by age and sex in **Table 1**. Mean daily dietary intakes ranged from 5.5 mg in non–breastfeeding infants to 9–11 mg in adolescents (i.e., age 11–18 y) and adults. Mean dietary intakes were similar for males and females aged ≤10 y (data not shown). For those aged >10 y, mean dietary zinc intakes averaged 3–4 mg higher in males than in females of the same age group ($P < 0.01$).

There was a pattern of increasing mean total zinc intake with increasing age. Mean total zinc intakes ranged from 5.5 mg in infants to ~13 mg in adults and were higher in adolescent and adult males than in females ($P < 0.01$). Mean total zinc intakes were ~0.7 mg higher in adolescents and 2.5–3.5 mg higher in adults compared with the mean dietary intake, indicating the contribution of supplements to total zinc intake.

In NHANES III, vitamin/mineral supplements were used by 39.5% of the U.S. population between 1988 and 1994 (data not shown). Supplement use increased with age and was more common in women and non-Hispanic whites. At least one zinc-containing supplement was reported by 37% of all sup-

TABLE 1

Mean and median daily dietary[1] and total zinc intake by age and sex in the U.S. population, 1988–1994

Age	Sample size	Dietary zinc (food only)		Total zinc intake (food and supplements)	
		Mean (SE)	Median (SE)	Mean (SE)	Median (SE)
		mg			
Total					
≥2 mo[2,3]	28,663	10.0 (0.04)	9.5 (0.04)	12.2 (0.11)	10.3 (0.05)
2–11 mo[3]	1620	5.5 (0.04)	5.5 (0.04)	5.5 (0.04)	5.5 (0.03)
1–3 y[3]	3309	6.4 (0.04)	6.3 (0.04)	7.1 (0.11)	6.4 (0.06)
4–6 y	2438	7.7 (0.06)	7.6 (0.08)	8.4 (0.15)	7.8 (0.08)
7–10 y	2088	9.1 (0.08)	8.6 (0.08)	9.6 (0.15)	8.7 (0.09)
11–18 y[2]	3260	10.4 (0.12)	10.3 (0.13)	11.1 (0.17)	10.5 (0.13)
19–50 y[2]	9307	10.9 (0.06)	10.5 (0.08)	13.4 (0.17)	11.5 (0.09)
51–70 y[2]	4018	10.0 (0.08)	9.7 (0.10)	13.3 (0.24)	10.8 (0.13)
71+ y	2623	9.2 (0.10)	8.9 (0.12)	12.7 (0.40)	9.7 (0.16)
Male					
≥2 mo[3]	13,922	11.9 (0.05)	11.8 (0.06)	13.7 (0.13)	12.2 (0.07)
11–18 y	1568	12.2 (0.12)	12.0 (0.11)	12.9 (0.21)	12.2 (0.13)
19–50 y	4435	13.2 (0.08)	12.9 (0.07)	15.3 (0.16)	13.3 (0.08)
51–70 y	1942	11.7 (0.10)	11.4 (0.13)	14.7 (0.31)	12.1 (0.15)
71+ y	1255	10.9 (0.15)	10.4 (0.11)	14.2 (0.46)	11.0 (0.14)
Female					
≥2 mo[2,3]	14,741	8.2 (0.04)	8.0 (0.03)	10.8 (0.15)	8.4 (0.04)
11–18 y[2]	1692	8.5 (0.11)	8.3 (0.16)	9.2 (0.16)	8.6 (0.14)
19–50 y[2]	4872	8.5 (0.05)	8.4 (0.05)	11.5 (0.26)	8.9 (0.07)
51–70 y[2]	2076	8.4 (0.11)	7.7 (0.10)	12.1 (0.31)	8.8 (0.18)
71+ y	1368	8.0 (0.12)	7.3 (0.17)	11.6 (0.48)	8.2 (0.25)
Pregnant	341	9.2 (0.21)	9.0 (0.29)	21.8 (1.04)	23.0 (3.43)
Lactating[4]	99	10.4 (0.29)	10.2 (0.39)	22.0 (2.41)	8.7 (5.63)

[1] Based on 1-day 24-h dietary recall adjusted by 1986 National Academy of Sciences method.
[2] Excludes pregnant and lactating females.
[3] Excludes infants and toddlers who were breast feeding.
[4] Includes 5 females who were also pregnant.

TABLE 2

Mean and median daily dietary[1] zinc intake by age, sex and race/ethnicity in the U.S. population, 1988–1994

Age	NHW Sample size	NHW Mean (SE)	NHW Median (SE)	NHB Sample size	NHB Mean (SE)	NHB Median (SE)	MA Sample size	MA Mean (SE)	MA Median (SE)
					mg				
Total									
≥2 mo[2,3]	10,533	10.1 (0.05)	9.6 (0.05)	8392	9.5 (0.05)	9.0 (0.05)	8421	10.0 (0.04)	9.5 (0.07)
2–11 mo[3]	903	5.4 (0.04)	5.4 (0.04)	284	5.6 (0.09)	5.7 (0.09)	280	5.6 (0.07)	5.5 (0.08)
1–3 y[3]	1012	6.4 (0.06)	6.3 (0.07)	980	6.5 (0.05)	6.3 (0.05)	1150	6.4 (0.07)	6.3 (0.06)
4–6 y	650	7.7 (0.07)	7.5 (0.10)	773	8.0 (0.05)	7.9 (0.06)	888	7.7 (0.09)	7.6 (0.09)
7–10 y	571	9.1 (0.11)	8.6 (0.10)	714	9.0 (0.09)	8.6 (0.09)	725	9.1 (0.11)	8.7 (0.14)
11–18 y[2]	842	10.5 (0.14)	10.4 (0.15)	1149	10.2 (0.09)	10.0 (0.14)	1107	10.4 (0.11)	10.1 (0.16)
19–50 y[2]	2861	10.9 (0.07)	10.5 (0.10)	3061	10.5 (0.09)	10.0 (0.11)	2981	11.2 (0.05)	11.0 (0.07)
51–70 y[2]	1851	10.1 (0.10)	9.8 (0.11)	1023	8.8 (0.10)	8.6 (0.10)	983	9.5 (0.12)	9.3 (0.15)
71+ y	1843	9.3 (0.12)	9.0 (0.14)	408	8.2 (0.16)	7.7 (0.22)	307	8.6 (0.18)	8.4 (0.21)
Male									
≥2 mo[3]	5028	12.0 (0.06)	11.9 (0.06)	4003	11.2 (0.07)	11.1 (0.08)	4263	11.5 (0.06)	11.6 (0.07)
2–11 mo[3]	455	5.5 (0.05)	5.5 (0.06)	145	5.6 (0.11)	5.8 (0.10)	149	5.6 (0.09)	5.5 (0.11)
1–3 y[3]	500	6.6 (0.07)	6.6 (0.08)	484	6.8 (0.06)	6.7 (0.09)	556	6.6 (0.06)	6.5 (0.07)
4–6 y	318	8.0 (0.09)	7.8 (0.09)	379	8.2 (0.08)	8.0 (0.12)	427	8.0 (0.08)	7.9 (0.10)
7–10 y	291	10.1 (0.19)	10.0 (0.29)	369	9.9 (0.13)	9.7 (0.12)	367	9.9 (0.17)	9.7 (0.19)
11–18 y	387	12.3 (0.15)	12.0 (0.17)	552	11.6 (0.16)	11.5 (0.20)	561	11.9 (0.11)	11.7 (0.14)
19–50 y	1308	13.2 (0.10)	13.0 (0.10)	1394	12.9 (0.09)	12.7 (0.09)	1553	13.2 (0.09)	13.0 (0.06)
51–70 y	899	11.9 (0.12)	11.5 (0.15)	489	10.3 (0.15)	9.9 (0.15)	486	11.1 (0.12)	10.8 (0.16)
71+ y	870	11.1 (0.16)	10.5 (0.13)	191	9.7 (0.21)	9.5 (0.14)	164	10.0 (0.27)	9.8 (0.28)
Female									
≥2 mo[2,3]	5505	8.3 (0.05)	8.1 (0.04)	4389	8.0 (0.05)	7.8 (0.04)	4158	8.2 (0.05)	7.9 (0.06)
2–11 mo[3]	448	5.3 (0.06)	5.2 (0.10)	139	5.6 (0.11)	5.7 (0.14)	131	5.5 (0.12)	5.4 (0.11)
1–3 y[3]	512	6.1 (0.08)	6.0 (0.09)	496	6.2 (0.07)	6.1 (0.09)	594	6.2 (0.12)	6.0 (0.13)
4–6 y	332	7.3 (0.10)	6.9 (0.15)	394	7.7 (0.08)	7.6 (0.15)	461	7.4 (0.16)	7.1 (0.18)
7–10 y	280	8.0 (0.04)	7.9 (0.05)	345	8.1 (0.07)	8.0 (0.09)	358	8.2 (0.06)	8.2 (0.09)
11–18 y[2]	455	8.5 (0.15)	8.3 (0.20)	597	8.7 (0.11)	8.5 (0.12)	546	8.8 (0.16)	8.4 (0.17)
19–50 y[2]	1553	8.5 (0.06)	8.4 (0.05)	1667	8.3 (0.07)	8.1 (0.07)	1428	8.6 (0.06)	8.4 (0.07)
51–70 y[2]	952	8.6 (0.13)	7.8 (0.11)	534	7.7 (0.16)	7.0 (0.12)	497	8.2 (0.22)	7.5 (0.26)
71+ y	973	8.1 (0.14)	7.4 (0.19)	217	7.3 (0.22)	6.5 (0.25)	143	7.2 (0.33)	6.8 (0.42)
Pregnant	82	9.2 (0.29)	9.0 (0.36)	109	9.3 (0.32)	9.1 (0.27)	143	9.0 (0.20)	8.7 (0.21)

[1] Based on 1-day 24-h dietary recall adjusted by 1986 National Academy of Sciences method.
[2] Excludes pregnant and lactating females.
[3] Excludes infants and toddlers who were breast feeding.
NHW, non-Hispanic white; NHB, non-Hispanic black; MA, Mexican American.

plement users, or 14.6 ± 0.58% of the overall population. One tenth of 1% of infants, 5.3% of children aged 1–10 y, 7.0% of adolescents aged 11–18 y, 16.8% of adults aged 19–50 y, 20.5% of adults aged 51–70 y, 20.4% of adults aged ≥71 y, 55.3% of pregnant females and 53.7% of lactating females were taking at least one zinc-containing supplement. The average daily contribution of supplements to total zinc intake was 0.96 mg (7.9%) for all ages and ranged from 0 mg in infants to 1.67 mg (13.8%) of total daily intake in adult females aged 51–70 y. Supplements accounted for 8.3 mg (38.2%) and 7.6 mg (34.4%) of total intake in pregnant females and lactating females, respectively.

Females who were pregnant or lactating had significantly higher mean dietary zinc intakes than their nonpregnant, nonlactating counterparts. Mean dietary intakes were 9.2 mg in pregnant females and 10.4 mg in lactating females compared with 8.5 mg in nonpregnant, nonlactating females of comparable age ($P < 0.01$). Mean total zinc intakes were ~22 mg in both pregnant and lactating females and ~10 mg higher, on average, than mean intakes for nonpregnant, nonlactating females ($P < 0.01$).

Mean and median dietary zinc intakes and total zinc intakes are shown by age, sex and race/ethnicity in **Tables 2** and **3**, respectively. Mean dietary zinc intakes were not statistically different among non-Hispanic whites, non-Hispanic blacks and Mexican Americans of the same age and sex group for age/sex groups aged <51 y. For males and females aged 51–70 y and ≥71 y, non-Hispanic whites had significantly higher mean dietary and total zinc intakes than non-Hispanic blacks ($P < 0.001$) and Mexican Americans ($P < 0.001$), with the exception of females aged 51–70 y. Total zinc intakes followed the same patterns for the oldest age groups. In addition, for adolescent males and females and males aged 19–50 y, total zinc intakes were significantly higher in non-Hispanic whites than in non-Hispanic blacks ($P < 0.001$).

For pregnant females, there were no significant differences in mean dietary zinc intakes by race/ethnicity (Table 2). Total zinc intakes were higher in non-Hispanic white pregnant females than in the other two race/ethnic groups, indicating the higher use of zinc-containing supplements in non-Hispanic whites ($P < 0.06$) (Table 3). [Note: There were insufficient sample sizes to report zinc intakes by race/ethnicity in lactating females.]

Table 4 shows that for 55.6% of the total population, the zinc intakes were "adequate." The percentage of the population with "adequate" total zinc intakes was highest in infants

TABLE 3

Mean and median total (diet and supplements) zinc intake by age, sex and race/ethnicity in the U.S. population, 1988–1994

Age	NHW			NHB			MA		
	Sample size	Mean (SE)	Median (SE)	Sample size	Mean (SE)	Median (SE)	Sample size	Mean (SE)	Median (SE)
					mg				
Total									
≥2 mo[2,3]	10,533	12.6 (0.15)	10.6 (0.08)	8392	11.0 (0.13)	9.4 (0.05)	8421	11.1 (0.10)	9.8 (0.08)
2–11 mo[3]	903	5.4 (0.04)	5.4 (0.04)	284	5.6 (0.09)	5.7 (0.09)	280	5.6 (0.07)	5.5 (0.08)
1–3 y[3]	1012	7.4 (0.16)	6.5 (0.08)	980	6.7 (0.08)	6.4 (0.06)	1150	6.9 (0.16)	6.3 (0.07)
4–6 y	650	8.5 (0.22)	7.7 (0.10)	773	8.4 (0.11)	7.9 (0.08)	888	8.2 (0.16)	7.7 (0.08)
7–10 y	571	9.8 (0.21)	8.8 (0.13)	714	9.3 (0.15)	8.6 (0.10)	725	9.3 (0.14)	8.7 (0.14)
11–18 y[2]	842	11.3 (0.21)	10.6 (0.13)	1149	10.6 (0.16)	10.1 (0.15)	1107	10.9 (0.13)	10.2 (0.15)
19–50 y[2]	2861	13.7 (0.22)	11.7 (0.12)	3061	12.6 (0.24)	10.7 (0.12)	2981	12.7 (0.13)	11.5 (0.08)
51–70 y[2]	1851	13.7 (0.26)	11.0 (0.17)	1023	10.5 (0.25)	9.0 (0.10)	983	11.5 (0.27)	9.8 (0.18)
71+ y	1843	12.9 (0.43)	9.8 (0.17)	408	9.7 (0.30)	8.2 (0.28)	307	11.3 (1.06)	9.1 (0.26)
Male									
≥2 mo[2,3]	5028	14.1 (0.16)	12.4 (0.09)	4003	12.4 (0.14)	11.4 (0.10)	4263	12.6 (0.15)	11.8 (0.08)
2–11 mo[3]	455	5.5 (0.05)	5.5 (0.06)	145	5.6 (0.11)	5.8 (0.10)	149	5.6 (0.09)	5.5 (0.11)
1–3 y[3]	500	7.7 (0.31)	6.7 (0.09)	484	7.0 (0.10)	6.7 (0.09)	556	7.3 (0.22)	6.6 (0.08)
4–6 y	318	8.5 (0.20)	7.9 (0.08)	379	8.8 (0.18)	8.2 (0.12)	427	8.4 (0.15)	8.0 (0.12)
7–10 y	291	10.8 (0.30)	10.2 (0.26)	369	10.3 (0.20)	9.7 (0.13)	367	10.1 (0.22)	9.8 (0.17)
11–18 y	387	13.1 (0.30)	12.3 (0.20)	552	11.9 (0.20)	11.6 (0.23)	561	12.4 (0.14)	11.9 (0.14)
19–50 y	1308	15.5 (0.19)	13.4 (0.11)	1394	14.6 (0.21)	13.0 (0.11)	1553	14.7 (0.25)	13.2 (0.09)
51–70 y	899	15.0 (0.29)	12.3 (0.18)	489	12.0 (0.44)	10.2 (0.16)	486	12.7 (0.32)	11.2 (0.12)
71+ y	870	14.4 (0.49)	11.1 (0.17)	191	11.1 (0.29)	9.7 (0.18)	164	11.3 (0.49)	10.3 (0.44)
Female									
≥2 mo[2,3]	5505	11.2 (0.21)	8.6 (0.07)	4389	9.7 (0.19)	8.1 (0.04)	4158	9.4 (0.09)	8.2 (0.07)
2–11 mo[3]	448	5.3 (0.06)	5.2 (0.10)	139	5.6 (0.11)	5.7 (0.14)	131	5.5 (0.12)	5.4 (0.11)
1–3 y[3]	512	7.0 (0.19)	6.1 (0.10)	496	6.5 (0.14)	6.2 (0.07)	594	6.6 (0.22)	6.1 (0.12)
4–6 y	332	8.4 (0.41)	7.1 (0.20)	394	8.0 (0.13)	7.7 (0.14)	461	8.0 (0.27)	7.2 (0.19)
7–10 y	280	8.6 (0.31)	8.0 (0.07)	345	8.3 (0.17)	8.0 (0.10)	358	8.5 (0.13)	8.2 (0.08)
11–18 y[2]	455	9.3 (0.22)	8.7 (0.17)	597	9.3 (0.22)	8.6 (0.11)	546	9.3 (0.19)	8.6 (0.18)
19–50 y[2]	1553	11.9 (0.34)	9.0 (0.09)	1667	10.8 (0.40)	8.5 (0.08)	1428	10.1 (0.14)	8.7 (0.08)
51–70 y[2]	952	12.6 (0.38)	9.0 (0.26)	534	9.4 (0.24)	7.5 (0.16)	497	10.5 (0.41)	8.1 (0.23)
71+ y	973	11.9 (0.51)	8.4 (0.30)	217	8.9 (0.51)	6.7 (0.28)	143	11.3 (1.88)	7.8 (0.56)
Pregnant	82	23.1 (1.44)	24.8 (3.03)	109	18.9 (1.54)	10.1 (0.92)	143	19.3 (1.25)	10.0 (2.74)

[1] Based on 1-day 24-h dietary recall adjusted by 1986 National Academy of Sciences method.

[2] Excludes pregnant and lactating females.

[3] Excludes infants and toddlers who were breast feeding.

NHW, non-Hispanic white; NHB, non-Hispanic black; MA, Mexican American.

aged 2–11 mo (96.3%) and lowest in young children aged 1–3 y (18.9%). The proportion of the population with "adequate" zinc intake was lower in females than in males for all age groups. Approximately 39% of adolescent females had "adequate" zinc intake compared with 62% of adolescent males. The proportion of adult males with "adequate" intakes declined from 77% in those aged 19–50 y to 44% in those aged ≥71 y. About 45% of adult females had "adequate" intakes with little change with age. Approximately 52% of lactating females and 59% of pregnant females were categorized as "adequate" based on the 1989 RDA.

DISCUSSION

The NHANES dietary and dietary supplement data can be used to estimate the risk of zinc deficiency and the "adequacy" and toxicity of zinc intake compared with estimates of zinc requirements. The interpretation of zinc intake is complicated by the relatively narrow range of adequate zinc intakes (Mertz 1995, National Research Council 1989), and measures of zinc status may indicate higher or lower levels of deficiency, "adequacy" and toxicity than intake alone.

The NHANES III data show that total zinc intakes increase

TABLE 4

Percentage of the U.S. population with "adequate"[1] zinc intake, 1988–1994

Age	Total	Male	Female
		% (SE)	
≥2 mo[2,3]	55.6 (0.62)	67.1 (0.78)	44.5 (0.87)
2–11 mo[2]	96.3 (0.57)	96.9 (0.83)	95.6 (0.86)
1–3 y[2]	18.9 (1.42)	20.4 (1.73)	17.3 (1.63)
4–6 y	51.5 (2.00)	59.2 (2.59)	43.2 (2.58)
7–10 y	77.1 (1.29)	86.9 (1.64)	66.6 (1.94)
11–18 y[3]	50.5 (1.43)	61.9 (1.64)	38.7 (2.22)
19–50 y[3]	60.7 (0.85)	76.7 (1.22)	44.6 (1.22)
51–70 y[3]	51.1 (1.25)	56.8 (1.73)	46.1 (1.66)
71+ y	42.5 (1.67)	43.9 (1.98)	41.5 (2.19)
Pregnant	—	—	59.4 (3.91)
Lactating	—	—	51.5 (9.42)

[1] Based on a total zinc intake at or above 77% of the 1989 RDA age/sex-specific value (National Research Coucil 1989).

[2] Excludes infants and toddlers who were breast feeding.

[3] Excludes pregnant and lactating females.

with age through early adulthood and are higher in adolescent and adult males than in females. Total zinc intakes are relatively stable during adulthood but decline slightly with decreasing energy intakes in the oldest age group, ≥71 y. The potential magnitude of underreporting of energy intakes that is well established with the 24-hr dietary recall method must also be considered in interpreting population zinc intakes (Bingham 1997, Briefel et al. 1997). However, the impact of potential underreporting on zinc estimates or intakes of foods containing zinc is not well known.

Total zinc intakes are "adequate" for most infants and >50% of males aged 4–70 y, based on the 1989 RDA. Young children aged 1–3 y, female adolescents and older persons aged ≥71 y have the lowest percentage of "adequate" zinc intakes. Other studies have also found these population groups to be most "at risk" of inadequate zinc intakes (Bales et al. 1994, Crawford et al. 1995, Johnson et al. 1994a, 1994b, Sandstead and Smith 1996, Walsh and King 1994, Wood et al. 1995). The large variability in "adequacy" between infants (96%), children aged 1–3 y (17%) and the remainder of the population suggests problems with the current RDA cutoffs. For children 1 y old, the RDA for zinc doubles from 5 to 10 mg daily, yet energy requirements do not increase as dramatically (National Research Council 1989).

The oral reference doses (RfD) developed by toxicologists as principles for recommending safe intakes are set at 21 mg/d for zinc (Mertz 1995). This level is only 6 mg higher than the RDA for men and pregnant females. The RfD for 2-y-old children is set at 3.6 mg/d, whereas the RDA for that age group is 10 mg/d (National Research Council 1989). This overlap for young children reinforces the need to reexamine recommended RDA intakes for the healthy population while protecting vulnerable populations using the RfD.

In general, zinc is considered to be a relatively nontoxic mineral at moderate levels. However, deviations from usual dietary practices, typically through high levels of supplementation, can be detrimental to health (Mertz 1995, Sandstead and Smith 1996, Wada and King 1994, Wood et al. 1995). The 1989 RDA committee noted that chronic ingestion of zinc supplements at a level of >15 mg/d is not recommended without medical supervision (Hunt 1996, National Research Council 1989). About 2.2 ± 0.19% of the total nonpregnant, nonlactating population reported taking >15 mg zinc/d from supplements alone (data not shown). This figure is highest among women aged 19–50 y at 3.7 ± 0.51% and in men aged ≥71 y at 3.5% ± 0.74%. About 40% of pregnant and lactating females reported daily zinc supplement intakes of >15 mg.

The RDAs have served as the benchmark of nutritional adequacy in the United States (National Research Council 1989). The traditional role of the RDA is to establish levels of intake of essential nutrients that, on the basis of scientific knowledge, are judged to be adequate to meet the known nutrient needs of practically all healthy persons. Scientific knowledge of the roles of nutrients has expanded to include not only the prevention of nutritional deficiency diseases but also the reduction of chronic disease risk. This requires a balanced and thoughtful approach, especially for nutrients such as zinc, which may have a relatively narrow range of adequate and unsafe intake levels.

It is possible that the current RDAs of 15 mg/d for men and pregnant women and 12 mg/d for nonpregnant or nonlactating females are no longer applicable. Canada and the United Kingdom have lower recommendations for zinc intakes than the 1989 RDAs (National Research Council 1989 and Hunt 1996). The NHANES III intake data will be useful for setting the future dietary reference intakes for zinc, which will replace the 1989 RDAs. Therefore, it is difficult to conclude that the percentage of the U.S. population with "inadequate" zinc intakes is necessarily too high. Before recommending an increased intake in zinc from supplements, it would be prudent to wait for further research and National Academy of Sciences recommendations to be issued relative to this trace mineral.

In summary, mean total zinc intakes are higher in males than in females and in non-Hispanic white adolescents and adults than in non-Hispanic blacks and Mexican Americans. Children aged 1–3 y, adolescent females and persons aged ≥71 y are potentially at greater risk of "inadequate" zinc intakes. Excessive intake of zinc did not appear to be a significant problem during 1988–1994; however, the increased use of multiple dietary supplements and drugs in population groups such as older persons may affect zinc status and should be monitored in future surveys. National surveys must continue to assess quantitative intakes from diet (i.e., foods and beverages) and dietary supplements and should incorporate immune status and health status indicators to more fully address the relationships between zinc status and health. The development of easy, reliable methods for assessing zinc status that could be incorporated into future NHANES surveys, along with quantitative intakes, would provide a more complete picture of zinc status in the U.S. population in the future.

LITERATURE CITED

Abdel-Mageed, A. B. & Oehme, F. W. (1990) A review of the biochemical roles, toxicity and interactions of zinc, copper and iron. I. Zinc. Vet. Hum. Toxicol. 32–39.

Anderson, G. H., Peterson, R. D. & Beaton, G. H. (1982) Estimating nutrient deficiencies in a population from dietary records: the use of probability analyses. Nutr. Res. 2: 409–415.

Bales, C. W., DiSilvestro, R. A., Currie, K. L., Plaisted, C. S., Joung, H., Galanos, A. N. & Lin, P. H. (1994) Marginal zinc deficiency in older adults: responsiveness of zinc status indicators. J. Am. Coll. Nutr. 13: 455–462.

Bingham, S. A. (1987) The dietary assessment of individuals: methods, accuracy, new techniques, and recommendations. Nutr. Abstr. Rev. 57: 705–742.

Briefel, R. R., Sempos, C., McDowell, M. A., Chien, S. & Alaimo, K. (1997) Dietary methods research in the third National Health and Nutrition Examination Survey: under reporting of energy intake. Am. J. Clin. Nutr. 65(suppl.): 1203S–1209S.

Cousins, R. J. (1996) Zinc. In: Present Knowledge in Nutrition (Ziegler, E. E. & Filer, L. J., eds.), chap. 29, pp. 293–306, ILSI Press, Washington, DC.

Crawford, P. B., Obarzanek, E., Schreiber, G. B., Barrier, P. & Goldman, S. (1995) The effects of race, household income, and parental education on nutrient intakes of 9 and 10 year old girls: NHLBI Growth and Health Study. Ann. Epidemiol. 5: 360–368.

Federation of American Societies for Experimental Biology, Life Sciences Research Office (Pilch, S. M. & Senti, F. R., eds.) (1984) Assessment of the zinc nutritional status of the U.S. population based on data collected in the second National Health and Nutrition Examination Survey, 1976–80. Prepared for the Food and Drug Administration under Contract No. FDA 223-83-2384, Life Sciences Research Office, Bethesda, MD.

Federation of American Societies for Experimental Biology, Life Sciences Research Office (Klasing, S. A. & Pilch, S. M., eds.) (1985) Suggested measures of nutritional status and health conditions for the third National Health and Nutrition Examination Survey. Prepared under for the Food and Drug Administration under Contract No. FDA 223-84-2059, Life Sciences Research Office, Bethesda, MD.

Federation of American Societies for Experimental Biology, Life Sciences Research Office. (1995) Prepared for the Interagency Board for Nutrition Monitoring and Related Research. Third Report on Nutrition Monitoring in the United States: Volumes 1 and 2. U.S. Government Printing Office, Washington, DC.

Feinleib, M., Rifkind, B., Sempos, C., Johnson, C., Bachorik, P., Lippel, K., Carroll, M., Ingster-Moore, L. & Murphy, R. (1993) Methodological Issues in the measurement of cardiovascular risk factors: within-person variability in selected serum lipid measures–results from the third National Health and Nutrition Examination Survey (NHANES III). Can. J. Cardiol. 9(D):87D–88D.

Gibson, R. S. & Ferguson, E. L. (1998) Assessment of dietary zinc in a population. Am. J. Clin. Nutr. 68(suppl.):430S–434S.

Hunt, J. R. (1996) Bioavailability Algorithms in Setting of Recommended Dietary Allowances: Lessons From Iron, Applications to Zinc. American Institute of Nutrition, Bethesda, MD.

Johnson, R. K., Guthrie, H., Smiciklas-Wright, H. & Wang, M. Q. (1994a) Characterizing nutrient intakes of children by sociodemographic factors. Public Health Rep. 414–420.

Johnson, R. K., Johnson, D. G., Wang, M. Q., Smiciklas-Wright, H. & Guthrie, H. A. (1994b) Characterizing nutrient intakes of adolescents by sociodemographic factors. J. Adolesc. Health 15: 149–154.

McDowell, M. A., Briefel, R. R., Warren, R. A., Buzzard, I. M., Feskanich, D. & Gardner, S. N. (1990) The dietary data collection system: an automated interview and coding system for NHANES III. Proceedings of the 14th National Nutrient Databank Conference. CBORD Group Inc., Ithaca, NY.

Mertz, W. (1995) Risk assessment of essential trace elements: new approaches to assessing recommended dietary allowances and safety limits. Nutr. Rev. 53: 179–185.

National Research Council, Food and Nutrition Board, Coordinating Committee on Evaluation of Food Consumption Surveys, Subcommittee on Criteria for Dietary Evaluation Nutrient Adequacy (1986) Assessment Using Food Consumption Surveys. National Academy Press, Washington, DC.

National Research Council (1989) Recommended Dietary Allowances, 10th ed. National Academy Press, Washington, DC.

Neter, J., Wasserman, W. & Kutner, M. H. (1985) Applied Linear Statistical Models, 2nd ed. Richard Irwin, Inc., Homewood, IL.

Sandstead, H. H. & Smith, C. (1996) Deliberations and Evaluation of Approaches, Endpoints, and Paradigms for Determining Zinc Dietary Recommendations. American Institute of Nutrition, Bethesda, MD.

Sempos, C. T., Looker, A. C., Johnson, C. L. & Woteki, C. E. (1991) The importance of within-person variability in estimating prevalence. In: Monitoring Dietary Intakes (Macdonald, I., ed.), ILSI Monographs, Springer-Verlag, Berlin.

Shah, B. V., Barnwell, B. G. & Bieler, G. S. (1996) SUDAAN Users Manual, Release 7.0. Research Triangle Institute, Research Triangle Park, NC.

U.S. Department of Agriculture, Agricultural Research Service (1996) Survey Nutrient Databases for NHANES III, Phase 1 (1993) and Phase 2 (1995). Riverdale, MD.

U.S. Department of Health and Human Services, National Center for Health Statistics (1994) Plan and Operation of the third National Health and Nutrition Examination Survey, 1988–94. Vital and Health Statistics 1(32), U.S. Government Printing Office, Washington, DC.

U.S. Department of Health and Human Services, National Center for Health Statistics (1996) Third National Health and Nutrition Examination Survey, 1988–94, Reference Manuals and reports (CD-ROM). Centers for Disease Control and Prevention, Hyattsville, MD; National Technical Information Service (NTIS), Springfield, VA: Acrobat .PDF format; includes access software: Adobe Systems Inc. Acrobat Reader 2 1.

U.S. Department of Health and Human Services, National Center for Health Statistics (1997) Healthy People 2000 Review, 1997. Public Health Service, Hyattsville, MD. DHHS Publication No. (PHS) 98-1256.

U.S. Department of Health and Human Services, National Center for Health Statistics (1998) Third National Health and Nutrition Examination Survey, 1988–94, CD-ROM, Series 11, No. 2A. Centers for Disease Control and Prevention, Hyattsville, MD.

Wada, L. & King, J. C. (1994) Trace element nutrition during pregnancy. Clin. Obstet. Gynecol. 37: 574–586.

Walsh, C. T., Sandstead, H. H., Prasad, A. S., Newberne, P. M. & Fraker, P. J. (1994) Zinc: health effects and research priorities for the 1990's. Environ. Health Perspec. 102(suppl. 2): 5–46.

Wood, R. J., Suter, P. M. & Russell, R. M. (1995) Mineral requirements of elderly people. Am. J Clin. Nutr. 62: 493–505.