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IZiNCG TECHNICAL BRIEF

Determining the risk of zinc deficiency: Assessment of dietary zinc intake

An assessment of the prevalence of inadequate intakes of dietary zinc can provide information on the risk of zinc deficiency in a population. Inadequate dietary intake of bioavailable forms of zinc is the most likely cause of zinc deficiency. Plant-based diets consumed in many low- and middle-income countries are often based on unrefined cereals and legumes. These foods contain high amounts of phytate, a substance that significantly inhibits the body's absorption of zinc. Other diets based on starchy roots or tubers have a low total zinc content.

There are five main steps to assessing the adequacy of zinc intake in a population (**Figure 1**). Each step is described below.

Step 1 Determine the survey design

Two levels of information can be drawn on population zinc intakes, as determined by the basic survey design.

1a. Survey designed to estimate the prevalence of inadequate zinc intake

The preferred survey design allows the description of the distribution of usual zinc intakes by a population; that is, both the mean and variance about the mean are estimated. When the distribution of usual zinc intakes is known, the prevalence of inadequate zinc intakes in the population can be estimated. In this case, food intake must be determined for two nonconsecutive days or three consecutive days. It is preferable that multiple days of intake data are collected for all individuals in the population. However, if this is not possible, then at least two non-consecutive days of dietary intake data from a sub- sample of ≥ 40 to 50 individuals per subgroup should be collected.

Figure 1: Flowchart summarizing steps in assessing the dietary adequacy of zinc intakes in populations

Step 1 Determine the survey design

Determine the distribution of usual zinc intakes: Collect at least two days of intake data for the entire sample, or at least for a subsample (i.e., ≥40 - 50 individuals per subgroup)
or Determine the mean zinc intake of the population: Collect one day of dietary intake data per individual

Step 2 Select a representative population sample

Estimate an adequate sample size based on:
Expected prevalence of inadequate zinc intakes
and The desired confidence interval.

Step 3 Determine food intakes

Use either weighed food records or 24-hour recalls, adapted for the population of interest.

Step 4 Estimate dietary intake of absorbable zinc

Based on food intakes, calculate the dietary intake of total zinc and total phytate.

Calculate the phytate:zinc molar ratio of the diet, or estimate the phytate:zinc molar ratio based on diet type. In addition, for non-pregnant and non-lactating adults, the amount of zinc likely to be absorbed may also be calculated.

Step 5 Determine the prevalence of inadequate zinc intakes

If the distribution of usual zinc intakes for the study population is known or can be estimated by applying an appropriate external variance ratio of the intra- to inter-individual variation in zinc intakes, one can determine the prevalence of zinc intakes below the EAR. The EAR is specific for age, sex, physiological status and the phytate:zinc molar ratio of the diet.

In addition, for non-pregnant and non-lactating adults ≥9y the prevalence of *absorbable* zinc intakes below the appropriate physiological requirement for absorbed zinc can also be estimated.

1b. Survey designed to estimate the mean zinc intake in a population

If dietary intake data can only be collected on one day per individual in the sample, then only the mean zinc intake of the population can be determined. This method measures average intake but cannot show intra-individual variability so the data cannot be used to provide a precise estimate of the prevalence of inadequate intakes. Such data can still be used to identify foods that are the primary contributors of zinc and other specific nutrients and anti-nutrients in the habitual diet, and to identify possible food vehicles for use in food fortification programs. It can also provide a rough estimate of the proportion of individuals with inadequate zinc intakes, as described in Step 5.

Step 2 Select a representative population sample

The sample size for the dietary survey must be large enough to ensure that it is representative of the population of interest. The sample size required depends on both the anticipated prevalence of inadequate zinc intakes and the desired degree of precision of the estimate, or the size of the confidence interval. For survey design 1a, at least 100 individuals per subgroup should be recruited.

The anticipated prevalence of inadequate zinc intakes can be determined from:

i. Pre-existing dietary data on a similar population group that provide an estimate of the proportion of individuals within the population whose usual zinc intakes fall below the Estimated Average Requirement (EAR);

ii. Often, pre-existing data on zinc intakes are not available. In this case, an indirect estimate derived from food balance sheet data may be used [1]. These data provide the estimated percent of the population within the country at risk of inadequate zinc intake, based on the national food supply of the country [2].

Table 1: Estimated sample sizes for dietary surveys assessing usual zinc intakes of individuals within a population by anticipated proportion of individuals with inadequate intakes and desired precision (half the width of 95% confidence interval)

Estimated proportion[1]	DESIRED PRECISION				
	±0.02	±0.03	±0.04	±0.05	±0.06
0.05	457	203	115	73	51
0.10	865	385	217	139	97
0.15	1225	545	307	196	137
0.20	1537	683	385	246	171
0.25	1801	801	451	289	201
0.30	2017	897	505	323	225
0.40	2305	1025	577	369	257
0.50	2401	1068	601	385	267

[1] Anticipated proportion of individuals with zinc intakes below the estimated average requirement (EAR).

The desired confidence interval should also be taken into account.

Example calculations of sample sizes based on estimated prevalence of inadequate intakes and desired confidence intervals are shown in **Table 1**. These sample sizes should be applied to each stratum or sub group of interest, based on age, sex, physiological status, or area of residence.

Step 3 Select a food intake measurement method

The next step is to select a method for measuring food intakes. Intakes can be measured using in-home weighed food records, 24-hour recalls, or 24-hour duplicate diet composites. Weighed food records require a trained interviewer to measure the quantity of each food consumed over one day and is generally the most accurate method of measuring food intake. In low-income countries, weighed food records are often the method of choice for illiterate populations. Detailed protocols for training the interviewers [3] and collecting weighed food records [4] are available elsewhere.

Alternatively, 24-hour recalls can be used. This method requires that portion sizes can be recalled

accurately and, again, that trained interviewers conduct the recalls. Several strategies are available to improve portion size estimates and to reduce memory lapses during the 24-hour recall interviews; details are available elsewhere [5][1]. It is advisable to confirm the feasibility, validity, and reproducibility of using this 24-hour recall method described in the dietary manual [3] for the specific population group and setting before adopting this procedure for the proposed study. Refer to IZiNCG Technical Brief no. 7 for available 24-hour recall tools.

In countries where local food composition values for zinc and phytate are not available, then 24-hour duplicate diet composites can be collected by a trained interviewer from each individual for chemical analysis of zinc and phytate, with repeats on ≥40-50 individuals per subgroup [6].

Food frequency questionnaires are also sometimes used for assessing absorbable zinc intakes but there are limited data on their validity to measure zinc intakes in low-income countries.

Step 4 Estimate the intake of absorbable zinc in the diet

There are three stages involved in assessing the intake of absorbable zinc in the diet: the total zinc and phytate intakes must be calculated, then the phytate:zinc molar ratio determined, and lastly the appropriate EAR selected.

4a. Calculate total zinc and phytate intakes

Intakes of both zinc and phytate can be calculated from the food intake data measured in Step 3, using an appropriate food composition database and dietary assessment software. Details on how to compile a local food composition table have been described [3]. Where possible, local food composition data for zinc and phytate should be used, as these can vary with both local soil conditions and food preparation and processing methods [3,7].

[1] Several strategies for improving portion size estimates are described in detail in the dietary manual especially compiled for measuring intakes of absorbable zinc (and iron) in lower-income countries [3].

Information on the zinc content of local foods may be found from regional and national centers of the Food and Agriculture Organization's (FAO) International Network of Food Data Systems (INFOODS) and in the first IZiNCG Technical Document [8]. Values for the phytate content of raw and processed plant-based staples are available in the FAO/INFOODS/IZiNCG Global Food Composition Database for Phytate. Data for the zinc and phytate content of local foods from six countries (Eygpt, India, Indonesia, Kenya, Mexico, and Senegal) are also available through the WorldFood Dietary Assessment System, 2.0. These food composition tables can be downloaded free of charge from the FAO/INFOODS website (http://www.fao.org/infoods/infoods/tables-and-databases/en/).

Note that the US Department of Agriculture (USDA) food composition database also contains a comprehensive list of values for zinc (but not phytate) which can be downloaded free of charge from their website. Phytate values for this USDA database can be purchased from the University of Minnesota Nutrition Coordinating Center.

4b. Calculate phytate:zinc molar ratio

If the intakes of zinc and phytate have been calculated from the food intake data, the next stage is to calculate the phytate:zinc molar ratio of the diets of each individual to provide an estimate of zinc absorption. These ratios are calculated for each individual using the following equation:

$$\frac{\text{mg phytate per day / 660}}{\text{mg zinc per day / 65.4}}$$

For example, if the phytate intake is 883 mg/d and the zinc intake is 7 mg/d, then the phytate:zinc molar ratio is 12.5. The mean dietary phytate zinc molar ratio may then be used to classify diets as having low (i.e., phytate:zinc molar ratios >18) or average (i.e., phytate:zinc molar ratios 4-18) zinc bioavailability [8]. If information on the phytate content of the diet cannot be calculated, then diets should be categorized as having low or average zinc bioavailability based on certain dietary

characteristics. For example, unrefined cereal and/or legume-based diets (eg., phytate:zinc >18) would have low zinc bioavailability, whereas mixed diets or refined plant-based diets (phytate:zinc 4-18) would have average bioavailability [8].

For non-pregnant, non-lactating adults ≥19y the total intakes of zinc and phytate for each individual can be used to estimate total absorbable zinc using the updated trivariate saturation response model of Miller et al. [9] described in the equation below [10].

$$TAZ = .05 * \left[0.033 * \left[1 + \frac{TDP}{0.68} \right] + 0.091 + TDZ - \sqrt{\left[0.033 * \left[1 + \frac{TDP}{0.68} \right] + 0.091 + TDZ \right]^2 - 4 * 0.091 * TDZ} \right]$$

Where TAZ = total absorbed zinc (mmol/day(d)); TDP = total dietary phytate (mmol/d); TDZ = total dietary zinc (mmol/d).

Example: Assuming a mean intake of total dietary zinc (TDZ) of 8.5 mg/d and a mean intake of total dietary phytate (TDP) of 990 mg/d from the Cameroon national food consumption survey [11], then:

i. Convert TDZ and TDP as mmol/d as follows:
Mean TDZ in mmol/d = 8.5 mg/d /65.4 = 0.13 mmol/d.
Mean TDP in mmol/d = 990 mg/d /660 = 1.5 mmol/d.

ii. Substitute TDZ = 0.13 mmol/d and TDP=1.5 mmol/d in equation.

$$TAZ = .05 * \left[0.033 * \left[1 + \frac{1.5\ mmol/d}{0.68} \right] + 0.091 + 0.13\ mmol/d - \sqrt{\left[.033 * \left[1 + \frac{1.5\ mmol/d}{0.68} \right] + 0.091 + 0.13\ mmol/d \right]^2 - 4 * 0.091 * 0.13\ mmol/d} \right] = 0.0414\ mmol/d$$

iii. Convert TAZ as mmol/d back to mg/d:
TAZ= 0.0414 × 65.4 = 2.7 mg/d.

Table 2: Estimated Average Requirement for zinc (mg/d) by life stage and diet type defined by IZiNCG (EAR) and EFSA (AR)

IZiNCG				EFSA		
Age, Sex	**Reference weight (kg)**	**EAR Mixed[1]**	**EAR Unrefined[2]**	**Age, Sex**	**Reference weight (kg)**	**AR**
6-11 months	9	**3**	**4**	**7-11 months**	**-**	**2.4**
1-3 years	12	**2**	**2**	**1-3 years**	**11.9**	**3.6**
4-8 years	21	**3**	**4**	**4-6 years**	**19.0**	**4.6**
9-13 years	38	**5**	**7**	**7-10 years**	**28.7**	**6.2**
				11-14 years, M	**44.0**	**8.9**
				11-14 years, F	**45.1**	**8.9**
14-18 years, M	64	**8**	**11**	**15-17 years, M**	**64.1**	**11.8**
14-18 years, F	56	**7**	**9**	**15-17 years, F**	**56.4**	**9.9**
≥19 years, M	65	**10**	**15**	**≥19 years, M**	**68.1**	**9.31[3]**
≥19 years, F	55	**6**	**7**	**≥19 years, F**	**58.5**	**7.61[3]**
Pregnacy				**Pregnancy**		
14-18 years	-	**9**	**12**	**Additional AR**	**-**	**1.3**
≥ 19 years	-	**8**	**10**			
Lactation				**Lactation**		
14-18 years	-	**8**	**9**	**Additional AR**	**-**	**2.4**
≥ 19 years	-	**7**	**8**			

[1]Mixed or refined plant-based diets [2]Unrefined plant-based diets [3]ARs (mg/d) for 600 mg/d phytate intake presented in table; ARs for adults for 300 mg/d phytate are 7.5 (M) and 6.2 (F); ARs for adults for 900 mg/d phytate are 11.0 (M) and 8.9 (F); ARs for adults for 1200 mg/d phytate are 12.7 (M) and 10.2 (F)1

4c. Select the appropriate EAR

The final stage is to select the most appropriate EAR to assess the adequacy of zinc intakes by life stage and diet type. IZiNCG has developed EARs appropriate for international use (**Table 2**). Note that the European Food Safety Agency (EFSA) has recently revised dietary reference values for zinc (**Table 2**; [10]), however these values are based on European reference body weight data, which may not be applicable in all settings. Until the EFSA AR values are adapted for international use [12], use of the IZiNCG EAR values will enable cross-country comparisons of the adequacy of zinc intakes.

Step 5 Estimating the prevalence of inadequate zinc intakes

The process of assessing the prevalence of inadequate zinc intake depends on the survey design chosen. If the preferred survey design is used—and food intakes are measured on two non-consecutive or three consecutive days (1a.)—the assessment involves first correcting the distribution of observed zinc intakes, generated in Step 4, to represent usual zinc intakes, and then applying the EAR cut-point method. If the less preferred survey design is used—wherein only a single day's intake is measured (1b.)— either an estimate of the coefficient of variation (CV) of usual intakes of the population must be used or an appropriate external variance ratio can be applied. Then the EAR cut-point method, which determines the proportion of individuals with zinc intakes below the EAR, can be applied.

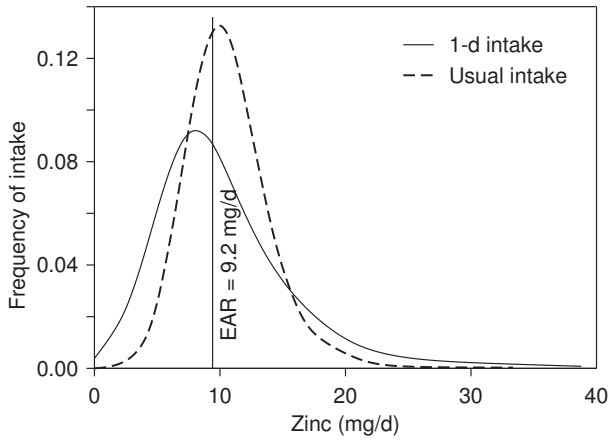
5a. Preferred survey design

i. Correct the observed zinc intakes to represent usual zinc intakes.

The distribution of observed zinc intakes in each of the age- and sex-specific subgroups must be adjusted to remove the variability introduced by day-to-day variation in an individual's zinc intake (i.e., intra-individual variation) [7]. This can be done using specialized software programs, e.g. PC Software for Intake Distribution Estimation (PC-SIDE) developed by Iowa State University [13] or the US National Cancer Institute (NCI) method [14], provided a series of replicate observations has been obtained on at least a subsample of individuals (e.g., ≥40-50) in each population subgroup of interest. For further information about these free of charge programs, refer to IZiNCG Technical Brief no. 7.

The adjustment process provides estimates of usual zinc intake distributions for each of the age- and sex-specific subgroups. An example comparing the adjusted distributions of usual zinc intakes with the observed zinc intakes for New Zealand adult females aged 19-50 years is shown in **Figure 2**. Note that the adjustment process used yields a distribution with reduced variability that preserves the shape of the original distribution [6].

Figure 2: Estimates of usual intake distribution for zinc for New Zealand adults obtained from 24-h recall data and adjusted with replicate intake data using the refined NRC method. The y-axis (frequency of intake) shows the likelihood of each level of intake in the population.



ii. Apply the EAR cut-point method to estimate the prevalence of inadequate zinc intakes.

The PC-SIDE or NCI programs should be used, running each age-and sex-specific subgroup and diet type separately (see Step 4) to determine the number of individuals with usual intakes below the appropriate zinc EAR.

iii. Estimate prevalence of inadequate intakes of *absorbable* zinc

This entails counting the number of non-pregnant or non-lactating adults with intakes of absorbable zinc below the appropriate physiological requirement for absorbed zinc. For IZiNCG, these are 1.86 and 2.69 mg/d for adult women and men ≥19 years, respectively [8]. For EFSA, these are 2.93 and 3.54 mg/d for adult women and men ≥19 years, respectively [10].

5b. Less-preferred survey design

i. When only a single day's intake is collected from each individual in the population, neither the true intra-individual variation, nor the distribution of usual zinc intakes in the survey population is known. Hence, for this survey design, the distribution of observed zinc intakes cannot be adjusted to usual intakes unless an external variance ratio is applied. Instead, a CV of usual zinc intakes must be assumed. The value recommended for this CV is 25%[2] and is based on data from a national survey of young people aged 4 to 18 years in the United Kingdom [15].

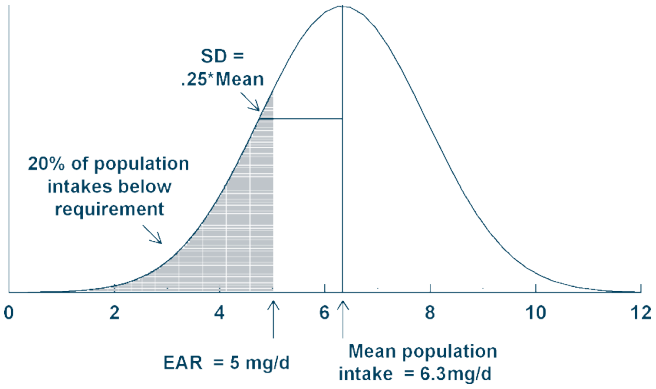
ii. Next, the EAR cut-point method can be applied to crudely estimate the proportion of individuals with inadequate intakes. This stage can be performed using a cumulative distribution function such as CDF.NORM in SPSS, where the SD of intakes is assumed to be 0.25 times the mean, as shown in the hypothetical example for adult women in **Figure 3**. Note that caution must be used when this approach is applied.

iii. If appropriate estimates of the intra-to interindividual variability (i.e., external variance ratio) are available for the subgroups of interest in the study population, then the PC-SIDE software can be applied to estimate the prevalence of inadequate intakes (albeit less precise) even though only one day of dietary intake data per individual has been collected. Note: this procedure must also be applied for any subgroup with fewer than 40 repeats.

[2] The coefficient of variation, 0.25, is represented as a percentage.

Finally, it is noteworthy that several other factors besides the survey objectives, such as availability of resources, will determine the final survey design.

Figure 3: Hypothetical, graphical representation of the estimation of the proportion of adult women with dietary zinc intakes below the estimated average requirement (EAR) for zinc from a typical mixed diet, assuming a mean intake of 6.3 mg/day and CV of the corrected distribution of usual intakes of 25%.



An elevated risk of zinc deficiency in the population is said to exist when 25% or more of the population have zinc intakes less than the EAR, irrespective of the survey design [8]. To assist with the interpretation of the risk of zinc deficiency, however, it is recommended to combine estimates of adequacy of zinc intakes with biochemical data on plasma or serum zinc concentrations and the prevalence of child stunting.

This Technical Brief was prepared by Dr. Rosalind S. Gibson and was reviewed by members of the IZiNCG Steering Committee.

Additional resources

FAO/INFOODS

In addition to the FAO/INFOODS/IZiNCG Global Food Composition Database for Phytate, the FAO/INFOODS Density Database is available at: http://www.fao.org/infoods/infoods/tables-and-databases/faoinfoods-databases/en/. FAO/INFOODS Guidelines for Checking Food Composition Data prior to the Publication of a User Table/Database, and FAO/INFOODS Guidelines for Food Matching are available at: http://www.fao.org/infoods/infoods/standards-guidelines/en/. Tables on weight yield of food and retention factors of food constituents published by the Federal Research Institute for Nutrition, Germany, are also available from FAO at: http://www.fao.org/uploads/media/bognar_bfe-r-02-03.pdf.

USDA National Agricultural Library

The USDA Table of Nutrient Retention Factors is available at: https://data.nal.usda.gov/dataset/usda-table-nutrient-retention-factors-release-6-2007. The USDA Table of Cooking Yields for Meat and Poultry is available at: https://data.nal.usda.gov/dataset/usda-table-cooking-yields-meat-and-poultry.

About IZiNCG

IZiNCG is the International Zinc Nutrition Consultative Group whose primary objectives are to promote and assist efforts to reduce global zinc deficiency through interpretation of nutrition science, dissemination of information, and provision of technical assistance to national governments and international agencies. IZiNCG focuses on identification, prevention and treatment of zinc deficiency in the most vulnerable populations of low-income countries.

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References

1. FAO. Food balance sheet. Available at http://faostat.fao.org/.

2. Wessells KR, Brown KH. Estimating the global prevalence of zinc deficiency: results based on zinc availability in national food supplies and the prevalence of stunting. PLOS ONE 2012:7e50568.

3. Gibson RS & Ferguson EL. An interactive 24-hr recall for assessing the adequacy of iron and zinc intakes in developing countries. HarvestPlus Technical Monograph Series 8. International Life Sciences Institute, Washington, DC, 2005.

4. Gibson RS. Nutritional Assessment: A Laboratory Manual. New York: Oxford University Press, 1993.

5. Gibson RS, Charrondiere UR, Bell W. Measurement errors in dietary assessment using self-reported 24-hr recalls in low income countries and strategies for their prevention. Adv Nutr 2017;8(6):980-991.

6. Gibson RS. Principles of Nutritional Assessment. 2nd Edition. New York: Oxford University Press, 2005

7. Alloway BJ. Zinc in soils and crop nutrition. Brussels: International Zinc Association, 2004.

8. IZiNCG. Assessment of the risk of zinc deficiency in populations and options for its control. Food Nutr Bull 2004;25:S94-S203. Available at: www. izincg.org.

9. Miller LV, Krebs NF, Hambidge KM. A mathematical model of zinc absorption in humans as a function of dietary zinc and phytate. J Nutr 2007;137:135-41.

10. European Food Safety Authority. Scientific opinion on Dietary Reference values for zinc. EFSA Panel on Dietetic Products, Nutrition and Allergies (NDA). EFSA Journal 2014;12(10):3844.

11. Engle-Stone R, Ndjebayi AO, Nankap M, Killilea DW, Brown KH. Stunting Prevalence, Plasma Zinc Concentrations, and Dietary Zinc Intakes in a Nationally Representative Sample Suggest a High Risk of Zinc Deficiency among Women and Young Children in Cameroon. J Nutr 2014;144:382-391.

12. Gibson RS, King JC, Lowe N. A review of dietary zinc recommendations. Food Nutr Bull 2016;37(4):443-460.

13. Nusser S, Carriquiry A, Dodd K, Fuller W. A semiparametric transformation approach to estimating usual daily intake distributions. J Am Stat Assoc 1996;91:1440-1449.

14. Tooze JA, Kipnis V, Buckman D, Carroll RJ, Freedman LS, Guenther PM, Krebs-Smith SM, Subar AF, Dodd KW. A mixed-effects model approach for estimating the distribution of usual intake of nutrients: the NCI method. Stat Med. 2010;29:2857-2868.

15. Gregory J, Lowe S, Bates CJ, et al. National Diet and Nutrition Survey. Young people aged 4 to 18 years. Volume 1: Report of the diet and nutrition survey. London: The Stationary Office, 2000.