A Critique of Two Methods for Assessing the Nutrient Adequacy of Diets

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ABSTRACT

The adequacy of diets can be assessed using several analytical approaches. This paper reviews two methods of assessment: a cutoff method, which estimates the percentage of the population having usual intakes below a given value; and a probability method, which assesses the percentage of the population whose usual intakes are below their individual requirements. First, the concept of usual nutrient intakes and the problems associated with estimating usual intake distributions are discussed. Next, the two methods of dietary assessment and their related assumptions are described and compared. The more specific inference of the probability method is shown to rely on its assumptions and data that are currently not available. While the cutoff method is simpler, its use may result in misclassification errors and its estimates are highly influenced by the cutoff standard selected.

INTRODUCTION

Food consumption surveys and associated estimates of intake of dietary components provide an important source of information for assessing the nutrient adequacy of diets in the U.S. population, and for monitoring nutritional status. Despite the widely accepted importance of diet in determining nutritional outcomes, dietary data alone cannot identify individuals at nutritional risk; however, the cost and the feasibility of using other methods have resulted in the general use of food consumption survey data for assessing the adequacy of nutritional intake in a population. In order to ensure that estimates of nutritional intake based on dietary survey data are valid, it is important to identify and understand the methods and criteria used for evaluation.

Determining the appropriate criteria to use in assessing the nutrient adequacy of diets within a population is basic to designing effective nutrition policies and programs. A recent National Research Council (NRC) report evaluates the criteria and methods used to make dietary assessments of populations (1). One method uses a cutoff criterion to calculate the relative size of the population whose usual or typical daily intake is below a specified standard. The standard may be set to provide for intakes above the needs of most individuals in the population, or it may represent more stringent levels of adequacy (2). In using such a standard, the cutoff method thus provides an estimate of the proportion of the population at risk for inadequate intake. However, individual requirements vary, and the cutoff approach necessarily assumes a common requirement for all individuals in the specified population. Because of this assumption, the NRC recommends an alternative method to assess the extent of inadequate dietary intake, referred to as the probability method (1), which combines information on the distribution of nutrient requirements and the distribution of usual intakes to obtain an estimate of the proportion of the population whose usual intake is below his/her requirement. While this second approach is, in principle, more attractive, it requires more information regarding both the distribution of requirements and the association between requirements and usual daily intake than does the cutoff method.

The purpose of this paper is to compare the cutoff and the probability method for assessing dietary adequacy, and to describe the most appropriate application of each method. While the two methods differ in their use of dietary requirements information, they both rely on estimates of the distribution of usual intake. The first part of the paper describes the concept of usual intake and some issues concerning estimation of usual intake distributions. The two methods of assessment are then defined and compared. Next, examples are provided to clarify the inferences that can be made with each method and to indicate the effect of their underlying assumptions. The final section provides a discussion of the problems in obtaining precise estimates of the level of inadequate nutrient intake in a population.

THE DISTRIBUTION OF USUAL INTAKE

A central concept in dietary evaluation and in the establishment of dietary recommendations is the usual daily nutrient intake of an individual (1,3). As commonly defined, usual intake is the long-run average of the daily intakes of a nutrient or dietary component for an individual. Operationally, the usual intake can be thought of as the average of daily intakes observed for an individual over a long period of time. The concept of usual intake as an indicator of nutritional status recognizes that an individual who has a low intake of a given dietary component on one day is not necessarily deficient (or at risk of being deficient) so far as that dietary component is concerned. It is low intake over a sufficiently long period of time that produces a dietary deficiency (4). A dietary deficiency exists when an individual's usual intake of the dietary component is less than the individual's requirement.

For a population, the distribution of usual intake describes the percentage of individuals in the population with usual intakes at specific levels. It provides a representation of the most and least common values for usual intakes and of the pattern of variability among the individual usual intakes. A good estimate of the usual intake distribution is crucial to providing good estimates from either of the assessment methods discussed here.

There are several ways to describe the shape of the usual intake distribution. The distribution is often summarized by a mean and standard deviation, which are useful summary statistics when the distribution is symmetric (e.g., if the usual intakes follow a normal distribution). However, if the distribution is not symmetric, a coefficient describing the degree and direction of skewness is useful. Another way of describing the usual intake distribution is by a function, called a density function, representing the pattern of usual intakes in the data. The bell-shaped curve for the normal distribution is such a function. A graph of a density function gives an indication of the percentage of individuals in the population with usual intakes at specific levels.

Because intakes cannot be negative, usual intake distributions tend to be skewed to the right (1, 5, 6). This shape results from the fact that while most usual intakes are clustered around some value, there typically are some individuals whose usual intakes are large relative to the bulk of the population. Thus, for many usual intake distributions, a normal (or symmetric) distribution is not a good approximation.

Nusser et al. (7) found that Weibull distributions, skewed to the right, provide a good fit to the usual intake distribution for many dietary components (see Figure 1). This family of distributions and other similar families (e.g., gamma distributions) are often more appropriate, because they do not allow negative intakes (as the normal distribution does) and because they include a wide range of shapes with varying degrees of skewness.

Estimated usual intake distributions should reflect only the variation in usual intake among members of the population, and should exclude day to day variability in daily intakes. In some cases, distributions of usual intake for a population are estimated from only one day of observed dietary intake data per individual in a sample from the population. Such observed dietary intake data contain variations both within an individual (day to day) and among individuals (person to person), and do not permit estimation of either type of variability in dietary intake. Thus, estimates of usual intake distributions based on only one day of intake data include unwanted within individual variability [see the NRC report (1) and Life Sciences Research office report (3) for a more detailed explanation of this issue]. The implication of including this unwanted individual variability in the estimated usual intake distribution is that the tails of the estimated distribution are extended too far; that is, too large a portion of the population is estimated to have an inadequate usual intake relative to some standard, leading to an overestimate of the percentage of population with inadequate diets. Figure 2 illustrates this phenomenon by comparing usual and mean intake distributions (based on fitted distributions for iron). Note that the one-day mean intake distribution indicates that 7.9 percent of the population has an intake below a level of three standard deviations, compared with an estimate of 1.9 percent from the usual intake distribution.

A far better estimate of the distribution of usual intake is obtained by collecting more than one day of data per individual, so that the effects of within individual variability in daily intakes can be separated from those of among individual variability. In order to account for within individual variability and to improve the estimates of usual intake, many food consumption surveys, including the U.S. Department of Agriculture's (USDA) nationwide food consumption surveys, collect more than one day of intake data per individual.

Details on methods of estimating usual intake distributions that remove day to day variability in daily intakes and which rely on a Weibull distributional assumption, can be found in Nusser et al. (7). An alternative methodology based on a nonparametric transformation approach is described in Nusser et al. (8).

METHODS OF ASSESSING THE ADEQUACY OF DIETARY INTAKE

Assessment of the adequacy of dietary intake for a population involves comparing an estimate of the population's usual intake distribution for a given dietary component with some measure of the population's requirements for that component. The two methods of determining nutritional adequacy discussed here are the cutoff and the probability methods. The type of nutrient requirement information utilized for these two methods differs considerably, as does the type of inference that can be made regarding adequacy of intake in the population.

Cutoff Method

The cutoff method uses a fixed requirement level as a criterion for determining adequacy of intake. Often, the RDA or a portion of the RDA is used as the cutoff standard. This approach has been widely used in evaluating dietary status (e.g., Ref. 9). Because individual intakes are not compared with individual requirements, individuals with intakes below the cutoff standard are said to be <u>at risk</u> for developing a nutritional deficiency.

A fundamental problem of the cutoff method for assessing dietary adequacy in a population, which was identified by the NRC, stems from the potential for misclassifiying individuals as having inadequate dietary intakes (1). Whenever a cutoff point is used, there will be individuals whose usual intake falls below the cutoff point, but who are meeting their own lower-than-average requirement. These individuals will be incorrectly identified as being at risk. Likewise, individuals considered to have adequate intakes may actually be at risk if their personal requirement is higher than the chosen cutoff point. The likelihood of these misclassifications occurring has been discussed in numerous editions of the RDA (4,10) and in the NRC report (1).

Simplicity is the main advantage of the cutoff method. Because of errors in misclassification, the cutoff method is more appropriate when there is little variation in requirements among individuals in the population for the given nutrient, or when relative comparisons are of interest, such as in assessing consumption patterns over time or among subgroups of the population. However, in practice, the cutoff method is often applied when the range of individual requirements is wide, causing the interpretation of the results of dietary surveys to be ambiguous. Precise inference about the percentage of individuals with inadequate intake in a population cannot be made using the cutoff method, nor can the groups with probable deficiencies be accurately identified. Only an estimate of the proportion of the population at risk for nutritional deficiency relative to the standard applied can be obtained.

Probability Method

The probability method is designed to estimate the proportion of individuals in the population whose intakes are less than their requirements (1). This method requires knowledge of the joint distribution of usual daily intakes and requirements for individuals in the population. Using this method, the proportion of individuals with deficient intakes can be estimated by considering the probability that intake is less than the requirement for an individual belonging to the population of interest.

Because the probability method relies on the bivariate distribution of usual intake and nutrient requirements, it requires more information than the cutoff method. Although estimated usual intake distributions are available, little information exists on requirement distributions for any dietary component. Also, for several some dietary components, intakes and requirements may not be independent. If they are not, as is probably the case for energy, then an estimate of the correlation between requirements and intakes is required to construct a joint distribution. Such data are extremely difficult to collect.

If independence between intakes and requirements can be verified or assumed, then the calculations for the probability method are straightforward for any distributional assumption. The calculations of the percentage of the population with inadequate intake follow the procedures proposed by the NRC (1).

When intakes and requirements are not independent, then the calculations are more difficult. If usual intakes and requirements can be assumed to have a bivariate normal distribution (i.e., both distributions are normal, or are transformed to normality using appropriate methods), and an estimate of the correlation between usual intakes and requirements is available, then the probability that intake is less than the requirement can be expressed in terms of a univariate normal distribution, namely, the probability that intake minus requirement is negative. Under these conditions, calculations are straightforward. A more general approach outlined in the appendix may be used when the usual intake and/or the requirement distribution is not normal and only an estimate of the usual intake-requirement correlation exists.

It should be noted that if transformations are required to obtain normality for the usual intake and requirement distributions, the transformation used for both the usual intake and requirement distributions must be identical. For example, if a log transformation produces normality for the usual intake distribution, then the log of the requirement distribution should also be normal. When a common tranformation cannot be found for both distributions the more general version of the probability method described in the appendix should be applied.

In sum, the probability method as stated in (1) relies on a number of assumptions whose validity is difficult to evaluate. Its effective use also relies on reasonable estimates of requirement distributions and in some cases on an estimated correlation coefficient for usual intakes and requirements, both of which are currently unavailable.

FACTORS AFFECTING INFERENCES OBTAINED FROM THE CUTOFF AND THE PROBABILITY METHODS

Both the probability method and the cutoff method provide measures of the inadequacy of dietary intake in a population. However, the estimates they provide are different. The following examples illustrate the way in which these estimates are calculated and their relative sensitivity to different parameters in the estimation process. The constructed examples are for protein, based in part on data from the U.S. Department of Agriculture's 1985 Continuing Survey of Food Intakes by Individuals (CSFII). Similar techniques would apply for other nutrients as well.

The Problem

For ease of explanation, it is assumed for this set of examples that both the usual intake distribution and the distribution of requirements for individuals in a population are approximately normal. The parameters of interest are the mean usual intake (μ_I) and the requirement (μ_R) of individuals in the population, the standard deviations of usual intake and requirement, σ_I and σ_R, and the correlation between requirement and usual intake (ρ). These parameters, along with the normality assumptions above, can be used to estimate the percentage of the population with deficient intake using the probability method, and the estimated percentage of the population at risk for nutrient inadequacy using the cutoff method. The specific calculations are described in more detail in the appendix, including alternative methods for nonnormal distributions.

Estimates Using the Probability Method

To estimate the prevalance of dietary inadequacy in the population using the probability method, the proportion of individuals in the population whose usual intake is less than their requirement is determined. For the example of protein, first assume that the standard deviation for both usual intake and requirement is 4g ($\sigma_I = \sigma_R = 4$), that the average usual intake is 6g greater than the average protein requirement ($\mu_I - \mu_R = 6$), and that the correlation between protein usual intake and requirement is 0.30 ($\rho = 0.30$). These assumptions yield an estimate that 10 percent of the individuals have a deficient intake of protein, as shown in Table 1 (for $\mu_I - \mu_R = 6$, $\sigma_I = \sigma_R = 4$, $\rho = 0.30$, the proportion of individuals with inadequate intake is equal to 0.10).

The estimated proportion varies depending on the correlation between usual intake and requirement and the extent of difference between mean requirement and mean usual intake. As shown in Table 1, the proportion of the population with inadequate usual intakes increases as the correlation coefficient (ρ) decreases; for a given correlation, the proportion with inadequate usual intakes decreases as the difference between the mean usual intake and mean requirement grows larger (i.e., as mean intake increasingly exceeds mean requirements).

From this example, it is clear that assuming independence when the requirement and usual intake are, in fact, correlated leads to an overestimate of the proportion of individuals with deficient usual intake, although the effect of this assumption may be relatively small. The problem is more severe when mean intake exceeds mean requirement by one or more standard deviations.

Estimates Using the Cutoff Method

An alternative for assessing the nutrient inadequacy in a population is the cutoff method, which estimates the probability that an individual's intake lies below a threshold value, such as the RDA. This corresponds to an estimate of the proportion of the population at risk for the specified level of dietary inadequacy. Under the cutoff method, this probability depends only on the intake distribution; knowledge of the requirement distribution and the correlation between intake and requirement is not necessary, although the level of intake causing dietary inadequacy is required to accurately determine the cutoff point. Again, the specific calculations are described in the appendix.

Under a normality assumption, the proportion of individuals at risk in the population estimated using the cutoff method is determined by the mean and the standard deviation of usual intakes in the population and by the cutoff point. To see how the usual intake mean and cutoff point affect the calculated proportion at risk, consider the following combinations of parameter values:

a) mean usual intake of 34, 36, and 38 grams;

b) standard deviation of usual intake of 4 and 5 grams; and

c) RDA proportions (k) ranging from 0.50 to 1.00.

The calculated proportions are presented in Table 2. As expected, the proportion at risk increases as the cutoff criterion increases (becomes more stringent), as the standard deviation increases (i.e., the variability of usual intakes increases), and as mean intake declines relative to the cutoff point. The estimates are very sensitive to the RDA proportion, k, selected.

Although the scenarios for the probability and cutoff method examples are comparable, it is evident that the probabilities in Table 2 bear no relationship to those presented in Table 1 for the probability method. This is because the cutoff method provides estimates of the degree of risk rather than actual level of inadequacy present in the population.

DISCUSSION

Two methods of assessment have been reviewed and evaluated by using hypothetical distributions. The recent NRC evaluation of methods of dietary assessment (1) recommends that the probability method be used whenever possible. However, its use is severely limited by the lack of information on nutrient requirements distributions, and perhaps, by the lack of estimates for the correlation between usual intakes and requirements. Problems may also arise in finding common transformations for both the usual intake and requirement distributions. Alternatively, the cutoff method is limited because it cannot take into account variability of individual requirements, and its use may thus lead to classification errors.

In fact, neither approach may yield prevalence estimates of nutrient inadequacy that are accurate enough to be used for the formulation of specific nutrition interventions. Moreover, the use of either approach may result in overestimates of the magnitude of inadequate nutrition in the population. In particular, the assumption of independence between requirement and intake may lead to overestimates of the proportion of the population with deficient intake when using the probability method. And, since the cutoff method is very sensitive to the cutoff value used, selecting a cutoff value that overestimates the intake at which deficiency may occur will generate overestimates of the population at risk of inadequate intake (the opposite error is also possible).

When the proportion of the population having or at risk of having dietary deficiency is overestimated, too many resources are diverted from other health-related nutrition programs to nutrition interventions aimed at eliminating nutrient deficiencies. When the problem is underestimated, those segments of the population in need are not targeted for assistance.

CONCLUSIONS

Inasmuch as food consumption survey data provide widely accessible indicators of the adequacy of nutrient intake, it is important to develop dietary assessments that appropriately rank dietary inadequacies and effectively target populations in need. These rankings often determine priorities for public interventions and nutrition education programs. The difficulty in determining precise estimates of the proportion of population at risk should not dissuade nutrition educators, policymakers, or program analysts from using dietary data in their evaluations. Indeed, more precise estimates of dietary adequacy from food consumption survey data will improve the design and implementation of nutrition interventions.

The problems identified in this paper highlight the need for caution in applying and interpreting methods to assess dietary adequacy in populations. While RDAs provide relatively simple standards for assessing potential problems in nutrient intake within a population, applying such fixed cutoff standards can be problematic particularly when the requirement for the specific nutrient is likely to vary widely in the population under consideration. And, if the probability method recommended by the NRC (1) is being considered as the basis of assessment, an evaluation of the validity of assumptions regarding the intake and requirement distributions is warranted, especially since reliable information on requirements distributions is generally not available.

Table 1. Proportion of individuals with deficient intake for different parameters of the intake and requirement distribution for protein based on the probability method ($\sigma_I = \sigma_R = 4$)

$\mu_I - \mu_R$	Correlation (ρ) 0	0.15	0.30	0.45
0	0.50	0.50	0.50	0.50
2	0.36	0.35	0.34	0.32
6	0.14	0.12	0.10	0.08
10	0.04	0.03	0.02	0.01

Table 2. Proportion of population at nutritional risk for varying risk criteria (k) and intake mean and standard deviation for protein based on the cutoff method

	$\sigma_I = 4$				$\sigma_I = 5$			
μ_I	k=0.50	k=0.65	k=0.80	k=1.00	k=0.50	k=0.65	k=0.80	k=1.00
36	0.000	0.030	0.420	0.977	0.003	0.070	0.460	0.950
38	0.000	0.015	0.240	0.933	0.001	0.030	0.290	0.885
40	0.000	0.002	0.110	0.840	0.002	0.010	0.170	0.790

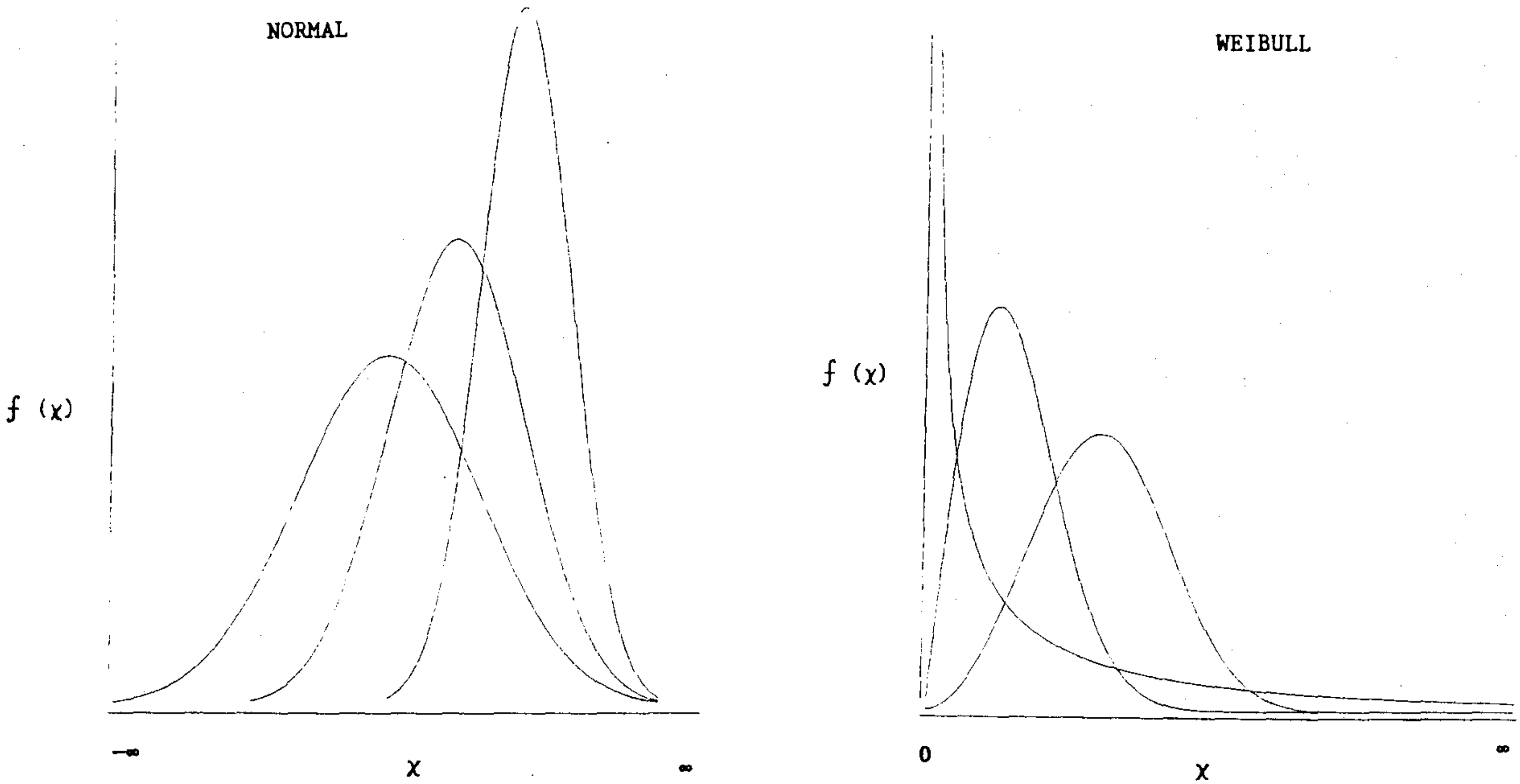

Figure 1. Plots of density functions for the normal and Weibull families. Note that normal distributions are symmetric and include negative values in their range. Weibull distributions are skewed to varying degrees and omit the possibility of negative values.

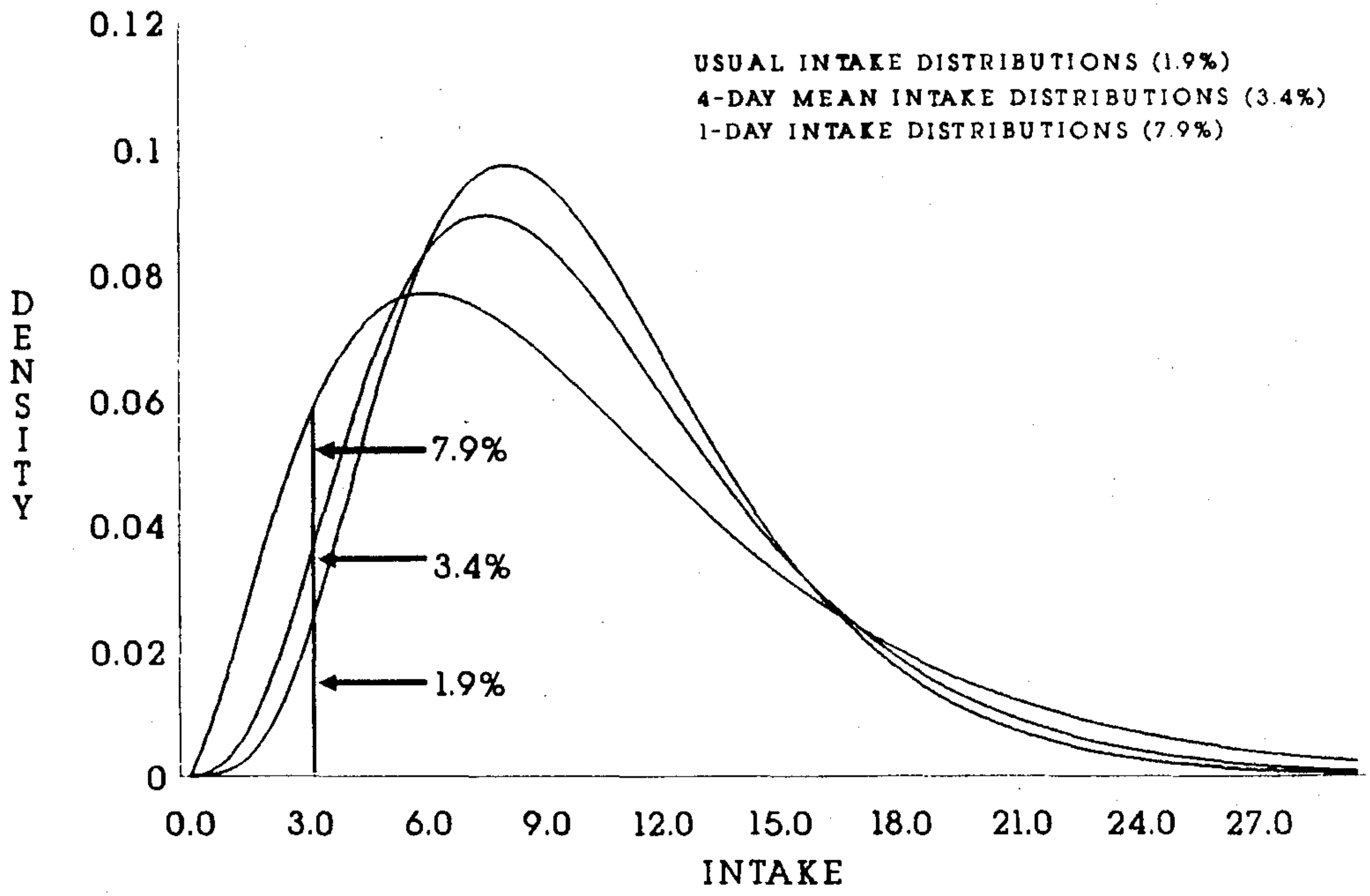

Figure 2. Usual intake and mean intake distributions with percent of population whose intake falls below 3 units.

APPENDIX

This appendix provides the specific calculation for the probability and cutoff methods of assessing nutrient inadequacy in populations based on dietary intake data.

Calculations for the Probability Method

We begin with the normal distribution scenario. A more general algorithm follows. Suppose that the joint distribution of intake and requirement of individuals in a population (I, R) is approximated by a bivariate normal distribution, with mean intake denoted by μ_I and mean requirement by μ_R, standard deviation of intake by σ_I and standard deviation of requirement by σ_R, and a correlation coefficient by ρ. In statistical notation, this is expressed as

$$\begin{pmatrix} I \\ R \end{pmatrix} \sim N \left[\begin{pmatrix} \mu_I \\ \mu_R \end{pmatrix}, \begin{pmatrix} \sigma_I^2 & \rho\sigma_I\sigma_R \\ \rho\sigma_I\sigma_R & \sigma_R^2 \end{pmatrix} \right].$$

The diagonal terms in the variance matrix (σ_I^2 and σ_R^2) refer directly to the variance of intake and requirements, respectively; the off-diagonal terms ($\rho\sigma_I\sigma_R$) indicate the correlation between requirements and intake. When the correlation coefficient, ρ, is not equal to zero, these terms are also nonzero.

The proportion of individuals with deficient intake (i.e., with intake less than requirement) is the probability of an individual in the population having intake (I) less than the requirement (R). Under normality, this is $\Pr(I < R) = \Pr((I - R) < 0)$ where $I - R \sim N\,[\mu_I - \mu_R, \sigma_I^2 - 2\rho\sigma_I\sigma_R + \sigma_R^2]$. This probability can be equivalently expressed in terms of the standard normal distribution as

$$\Pr\,(Z < z_0)$$

where $Z \sim N(0, 1)$ and $z_0 = -(\mu_I - \mu_R)[\sigma_I^2 - 2\rho\sigma_I\sigma_R + \sigma_R^2]^{-1/2}$.

For the example of protein, suppose that the standard deviation for both intake and requirement is 4 g ($\sigma_I = \sigma_R = 4$), that average intake is 6 g greater than the average protein requirement ($\mu_I - \mu_R = 6$), and that the correlation between protein intake and requirement is 0.30 ($\rho = 0.30$). Then z_o is calculated as

$$z_o = -(6)\ [\ 4^2 - 2(0.3)(4)(4) + 4^2]^{-1/2}$$

$$= -1.27 \quad .$$

Using a standard normal table, the estimate of the proportion of the population with inadequate intake is

$$\Pr\ (Z < -1.27) = 0.10 \quad .$$

That is, 10 percent of this population has deficient protein intake.

A more general form of the probability method is also available that does not require normality or independence assumptions. If a joint distribution of requirement and intake, represented by density $f_{I,R}\ (x,y)$, is available, the proportion of the population with deficient intake can be calculated as

$$\Pr\ (I < R) = \int_o^\infty \int_o^y f_{I,R}\ (x,y)\ dx\ dy.$$

A special case would be to assume bivariate normality for the joint distribution. Another special case exists where usual intake and/or requirement distributions are not normal, but independence exists between intake and requirement. In this case, given an intake distribution (for example, a density denoted f_I) and a requirement distribution (f_R), the proportion of individuals with inadequate intake can be calculated as:

$$\Pr\ (I < R) = \int_o^\infty \int_o^y f_I\ (x)\ f_R\ (y)\ dx\ dy.$$

Calculations for the Cutoff Method

The cutoff method of assessing the proportion of the population at risk for nutrient deficiency requires calculating the probability that an individual's usual intake lies below a cutoff point, typically some proportion of the RDA. That is, given an estimate of the usual intake distribution,

$$\Pr\,[I < k(\mathrm{RDA})]$$

is determined, where k is a proportion of the RDA.

Consider the calculation first under a normality assumption; a more general explanation is noted below. If usual intake is assumed to be normally distributed with mean μ_I and standard deviation σ_I, the probability statement just given can be expressed in terms of the standard normal distribution. Given that $Z \sim N\,(0,1)$, then this proportion can be calculated as

$$\Pr(Z < z_o'),$$

where $z_o' = \sigma_I^{-1}[k(\mathrm{RDA}) - \mu_I]$.

As an example, suppose that the RDA for protein is 44 g (RDA = 44), the mean protein intake is 38 g (μ_I = 38), the standard deviation for protein intake is 4 g (σ_I = 4), and that k = 0.65. Then

$$z_o' = (4)^{-1}[\ 0.65\ (44) - 38\ ]$$

$$= -2.18 \quad .$$

From the standard normal table, the proportion of the population at risk is

$$\Pr\,(Z < -2.18) = 0.015 \quad .$$

Hence, 1.5 percent of this population is at risk for protein deficiency.

As with the probability method, a more general cutoff method formulation is available. Given a usual intake distribution (say, a density denoted f_I) and a cutoff point c, the proportion of the population at nutritional risk relative to the cutoff point c is

$$\Pr\ (I < c) = \int_0^c f_I(x)\ dx.$$

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