History of Nutrition: The Long Road Leading to the Dietary Reference Intakes for the United States and Canada[1–3]

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ABSTRACT

The Dietary Reference Intakes (DRIs) are reference values to guide the planning and assessing of nutrient intakes in the United States and Canada. The DRI framework was conceptualized in 1994, and the first reports were issued from 1997–2004, based on work by expert panels and subcommittees under the guidance of the Food and Nutrition Board of the Institute of Medicine. Numerous conventions, challenges, and controversies were encountered during the process of defining and setting the DRIs, including the definition of the framework, the use of chronic disease endpoints, lack of data on requirements for children and youth, and methods for addressing nonessential bioactive substances with potential health benefits. DRIs may be used to plan and assess the nutrient intakes of both individuals and population groups, but the new paradigm particularly improved methods used for groups. It is now possible to estimate both the prevalence of inadequate intake and the prevalence of potentially excessive intake within a group. The DRIs have served as a potent influence on national nutrition policies, including those related to dietary guidance, food labeling, nutrition monitoring, food assistance programs, and military nutrition standards. Because of this important impact on nutrition policy, the DRIs must be based on the best possible and most up-to-date science. Unfortunately, no updates to specific DRIs are currently planned. Despite the long and challenging road that led to the current DRIs, it must not finish in a dead end. Monetary resources and political will are crucial to maintaining and continuously updating the DRIs. *Adv Nutr* 2016;7:157–68.

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Introduction

The DRIs are reference values to guide the planning and assessing of nutrient intake in the United States and Canada. The DRIs consist of several types of reference values, which are intended to reduce the risks of both nutrient inadequacy and excessive nutrient intake, as shown in **Table 1**. One or more DRI values are available for 51 nutrients, including vitamins, minerals, macronutrients, and energy. The rationales for each reference value were issued in a series of initial DRI reports (2–7) between 1997 and 2004, and subsequently followed by one update focused on calcium and vitamin D in 2011 (8). In addition, 2 reports detailing the proper uses of DRIs are available (9, 10), as is a book summarizing reports issued through 2004 (1). Totaling nearly 5000 pages, these reports represent the work of hundreds of scientists who served on the various panels and committees convened by the Food and Nutrition Board (FNB)[10] of the Institute of Medicine (IOM). It has indeed been a long road leading to the DRIs.

The history of the development of the DRIs is presented below, beginning with information on the advent of the DRI paradigm, followed by a discussion of some of the challenges, conventions, and controversies. The third section presents some of the expanded uses, and a few misuses, of the

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[10] Abbreviations used: AI, adequate intake; DoD, Department of Defense; EAR, estimated average requirement; FNB, Food and Nutrition Board; IOM, Institute of Medicine; MDRI, Military Dietary Reference Intake; RCT, randomized controlled trial; RNI, Recommended Nutrient Intake; UL, tolerable upper intake level; WIC, Special Supplemental Program for Women, Infants, and Children.

DRIs, and the fourth section illustrates some of the many ways in which the DRIs have influenced nutrition policies in the United States and Canada. Finally, the current status of the DRIs and what the future may hold for the ongoing improvement of these important reference values is discussed.

The Advent of the DRI Paradigm: Why it Improved upon the Recommended Dietary Allowances

The first RDAs for protein, energy, and 8 vitamins and minerals were established in 1941 by the US National Research Council at the request of the National Defense Advisory Commission (11). They were developed to serve as a basis for food relief efforts both in the United States and internationally, where war or economic depression had resulted in malnutrition or starvation, and were subsequently adopted in Canada and to some extent in England (12).

From this first report of 18 pages, revisions were periodically released by the FNB over the following ≥40 years, the last in 1989 (13) consisting of 273 pages. The number of vitamins and minerals in addition to protein and energy grew from the original 8 to 25 in 1989 as a result of growing information and evidence about the role of specific nutrients in deficiency diseases. Canada first set its own dietary standards in 1938, and then revised them periodically through 1990 (1). Beginning in 1983, the Canadian standards were named the Recommended Nutrient Intakes (RNIs) for Canadians. Although over the decades after World War II many other countries developed their own nutrient standards and allowances, many were based directly on the RDAs from the United States, which became the primary scientific basis for nutrition education, labeling, and design of food-based dietary guidance both in the United States and internationally.

Research on the role of diet in diseases beyond those caused by nutrient deficiencies began to emerge, and, in 1989, the FNB also released the Diet and Health report (14), which reviewed the role of specific nutrients and food components in the risk of chronic noncommunicable diseases, such as cardiovascular disease and cancer. The evolving emerging evidence of relations between diet and nutrients and chronic disease led to nutrition-related public health concerns that were increasingly focused on chronic disease and overconsumption.

An additional impetus to a retooling of the approach was the growing use of RDAs in ways that were not scientifically robust. Because only one reference value for a nutrient was available (a recommended daily intake amount for a broad age and sex group), little guidance or information could be derived upon which to determine at what point below that value an individual's intake would be inadequate, or where the intake of a population group under study might be considered inadequate—fundamental data needed when determining which nutrients should be considered for inclusion in fortification programs, or what to include in supplemental food packages provided to targeted subgroups such as those in the Special Supplemental Program for Women, Infants, and Children (WIC) in the United States, for example.

New approaches emerged to identify those at true risk of inadequacy or excess as part of nutrient recommendations, such as the first use of 3 dietary reference values in the United Kingdom report in 1991 (15). These included a lower level at which deficiency would be considered to exist in almost all, an average requirement, and a higher level that would be adequate for almost all in the age and sex group to which it pertained. This approach to identify potential adverse effects of excessive nutrient intake was of critical importance for the regulation of food fortification by federal agencies, because technology was making it possible to fortify foods with nutrients at high, almost pharmacologic, amounts. Thus, guidance from a reputable source about the potential adverse effects of excessive nutrient intake had become an important need of federal agencies. Exploration of multitiered nutrient recommendations was initiated by the FNB, culminating in a 1994 white paper that identified the increased use and misuse of the single reference values and the lack of reference values related to chronic disease endpoints, and asked the scientific and government communities for their input on a proposed expanded framework for reference values (16).

The DRIs, as they came to be termed, are shown in Table 1. They were conceptually based on the need to address multiple users and meet multiple needs, including labeling, limits for food fortification, and ability to assess the adequacy of diets of specific population groups. The primary working tenets of the DRI process were, and continue to be, as follows:

- Reference values related to nutrient adequacy [the estimated average requirement (EAR) and adequate intake (AI)] should be based on requirements for specific biochemical functions if possible, but can be based on less specific physiologic outcomes if significant data are available;
- Functional criteria must be associated with health benefit;
- A distribution of requirements should be defined for each nutrient, with the EAR as its mean. For nutrients with a normal distribution, the RDA is then calculated as the EAR plus 2 standard deviations, thus covering ~98% of the population;
- Desirable intake (usually where chronic disease is involved) should be based on intake over a lifetime;
- Food components that play a role in maintaining health are included (e.g., fiber);
- Reference values for biologically related age groups are provided;
- Reference values for intake levels beyond which there is a potential for adverse effects are included where data are available;
- Where it is not possible to estimate an average requirement and a corresponding RDA, a surrogate recommended intake is provided, but it is not called an RDA, but, rather, an AI or acceptable macronutrient distribution range; and
- Specific guidance is provided on using the multiple reference values in statistically defensible methods to evaluate intake and plan the diets of individuals and groups.

The major milestones in developing the DRIs are shown in **Table 2**. The DRI framework was conceptualized in 1994 and modified over the intervening 10 y. The reports, issued from 1997–2004, were developed by expert panels and subcommittees under the guidance of the FNB Standing

TABLE 1 Definitions and uses of the categories of DRIs for the United States and Canada[1]

Category	Definition[2]	Uses for individuals	Uses for groups
EAR	The average daily nutrient intake level that is estimated to meet the requirements of one-half of the healthy individuals in a particular life stage and gender group.	Assess the probability of inadequacy.	Assess the prevalence of inadequacy; plan intake to ensure a low prevalence of inadequacy.
RDA	The average daily dietary nutrient intake level that is sufficient to meet the nutrient requirements of nearly all (97.5%) healthy individuals in a particular life stage and gender group; set at 2 SD above the mean requirement (EAR).	Plan intake with a low probability of inadequacy.	Not used for groups.
AI	The recommended average daily intake level based on observed or experimentally determined approximations or estimates of nutrient intake by a group of apparently healthy people that are assumed to be adequate; provided when an EAR and RDA cannot be determined.	Assess and plan intake when an RDA is not available.	Assess and plan mean intake when an RDA is not available.
UL	The highest average daily nutrient intake level that is likely to pose no risk of adverse health effects to almost all individuals in the general population.	Assess potentially excessive intake; plan intake that does not exceed this level.	Assess the prevalence of potentially excessive intake; plan intake to ensure a low prevalence of potentially excessive intake.
EER	The average energy intake that is predicted to maintain energy balance in a healthy individual at a specific level of energy expenditure.	Assess and plan appropriate energy intake.	Assess and plan appropriate energy intake.
AMDR	The range of intake of protein, fat, and carbohydrate that is associated with a reduced risk of chronic disease, yet can provide adequate amounts of essential nutrients.	Assess whether macronutrient intake is outside the ranges; plan macronutrient intake within the ranges.	Assess the prevalence of macronutrient intake outside the ranges; plan macronutrient intake within the ranges.

[1] AI, adequate intake; AMDR, adequate macronutrient distribution range; EAR, estimated average requirement; EER, estimated energy requirement; UL, tolerable upper intake level.
[2] See reference 1 for more details.

Committee on the Scientific Evaluation of Dietary Reference Intakes to ensure a coordinated approach as new nutrients were reviewed. Before the initiation of the first panel, Health Canada became a partner in funding and supported Canadian scientist involvement, with the US Department of Health and Human Services coordinating United States participation for a number of federal agencies. Thus the DRIs are now jointly developed and used in both Canada and the United States.

Conventions, Challenges, and Controversies in Setting the DRIs

The establishment of harmonized DRIs between Canada and the United States was a pioneering venture that challenged each of the review panels to make decisions beyond conventions that had been established in setting previous dietary recommendations or planned a priori for the new paradigm of setting an EAR, RDA, and tolerable upper intake level (UL). A thoughtful review of the entire process of establishing the initial DRIs (2–7, 9, 10) was carried out by a working group that culminated in a workshop and publication in 2008 (19). A reflection of key aspects of the challenges and controversies that arose in the context of planning for future DRIs is provided in this section and highlighted in **Table 3**.

Framework definition. Although indicators of adequacy were defined for each nutrient in the first DRI reports (2–7), there was no consistent analytic framework in which the context for the indicators was described. An analytic framework was subsequently proposed in 2009 (20), and provided a link between nutrient exposure and clinical or disease outcome for which a strength of association could be defined, depending on the availability of clinical outcome data, or, if lacking, then defined based on an indicator marker and/or surrogate marker that was deemed to best predict the clinical outcome. Such indicators used in the first reports included biochemical, metabolic, or functional biomarkers, but often they were not considered to be validated and/or dose–response data were not available. Such indicators must be on the causal pathway to disease or clinical outcome to be valid. This approach was used in the 2011 update of the DRIs for calcium and vitamin D (8), and it produced reasonable evidence for bone health outcomes but was not applicable to other health outcomes, primarily because of lack of valid surrogate indicators of the disease outcomes.

Chronic disease endpoints. Although a strategy to meet the goal of setting nutrient intake recommendations by applying chronic disease endpoints with the goal of disease prevention was an a priori goal of the DRIs for all reports, the scientific

TABLE 2 Milestones in setting Dietary Reference Intakes for the United States and Canada

Date report issued	Institute of Medicine report (reference number)
1994	How should the Recommended Dietary Allowances be revised (12)?
1997	Dietary Reference Intakes for calcium, phosphorus, magnesium, vitamin D, and fluoride (2)
1998	Dietary Reference Intakes. A risk assessment model for establishing upper intake levels for nutrients (17)
1998	Dietary Reference Intakes for thiamin, riboflavin, niacin, vitamin B-6, folate, vitamin B-12, pantothenic acid, biotin, and choline (3)
2000	Dietary Reference Intakes for vitamin C, vitamin E, selenium, and carotenoids (4)
2001	Dietary Reference Intakes for vitamin A, vitamin K, arsenic, boron, chromium, copper, iodine, iron, manganese, molybdenum, nickel, silicon, vanadium, and zinc (5)
2002	Dietary Reference Intakes for energy, carbohydrate, fiber, fat, FAs, cholesterol, protein, and amino acids (macronutrients) (6)
2000, 2003	Applications in dietary assessment (9) and applications in dietary planning (10)
2004	Dietary Reference Intakes for water, potassium, sodium, chloride, and sulfate (7)
2006	Dietary Reference Intakes. The essential guide to nutrient requirements (1)
2007	Dietary Reference Intakes research synthesis: Workshop summary (18)
2008	The development of DRIs 1994–2004: Lessons learned and new challenges: Workshop summary (19)
2011	Dietary Reference Intakes for calcium and vitamin D (8)

evidence to support a direct nutrient exposure and disease risk reduction paradigm did not exist for most nutrients. The exceptions were for fluoride and dental caries, dietary fiber and coronary heart disease, sodium and hypertension, potassium and salt sensitivity/hypertension, and calcium and bone fractures. In addition, the DRIs provided adequate macronutrient distribution ranges for macronutrients that are based in part on hypothesized links to chronic disease from epidemiologic studies rather than experimental data. The shortfall in scientific evidence for chronic disease outcomes relates to lack of data from randomized controlled trials (RCTs) and lack of dose–response data. Furthermore, unlike with studies of the effects of drugs, it is difficult to examine the effects of single nutrients independent of other dietary factors, and thus difficult to demonstrate a dose–response relation for a single nutrient in the absence of other simultaneous changes.

When data on nutrient–disease relations existed, the observations from RCTs often were not consistent with the findings from observational data that had demonstrated a significant association between a nutrient exposure and disease risk reduction. Such inconsistent findings are evident

TABLE 3 Challenges in setting and revising DRIs for the United States and Canada[1]

Type of challenge	Examples
Lack of an analytic framework for EARs	No analytic framework was specified for most nutrient DRIs, with the exception of calcium and vitamin D in the 2011 report
Lack of analytic models for assessing chronic disease outcomes for EARs/RDAs	Only fluoride, dietary fiber, sodium, potassium, and calcium have chronic disease outcomes
For infants and children, a paucity of primary research on nutrient needs and adverse effects, thus leading to imputed values that may not be accurate	About 60% of the DRIs for children 7 mo–18 y are imputed. This led to wide variation in EARs/RDAs across sequential age groups and ULs for infants and young children that lead to very high prevalences of potentially excessive intakes (i.e., zinc and vitamin A)
Unclear if the current approaches to DRI development can be applied to standards for bioactive non-nutrient food components	α-Carotene, lutein, zeaxanthin, ω-3 FAs, and silicon were considered, but no DRIs were set for these bioactives
Efforts should be made to replace AIs with EARs/RDAs whenever possible	Neither the probability of inadequacy (for individuals) nor the prevalence of inadequacy (for groups) can be estimated for nutrients with an AI
EARs for nutrients with improbably high prevalences of inadequacy and with no clinical or biochemical indicators of adverse effects should be reviewed	The vitamin E prevalence of inadequacy is consistently ~90% across adult and children's age groups
UL framework needs review	Defining a distribution of adverse effects, rather than a single point, should be considered. Level of severity of toxic effects needs to be examined as well, because adverse effects vary from trivial to serious depending on the nutrient in question
Better methods of education on appropriate uses of the DRIs should be made available and journal editors need to institute more rigorous review of inappropriate uses	Incorrect use of the DRIs continues to appear in peer-reviewed papers
Easier access to DRI reports and updates should be considered	Consolidated information on the DRIs, perhaps as a CD, would be useful
A regular review process for existing DRIs is needed	The first DRIs were set in 1997, and only calcium and vitamin D have been reviewed since 2004
Stable funding for DRI activities going forward is crucial	Currently there is no funding for DRI activities. Given the many crucial applications of the DRIs for nutrition policy, a guaranteed budget is needed

[1] AI, adequate intake; CD, compact disc; EAR, estimated average requirement; UL, tolerable upper intake level.

for vitamin D for various health and disease outcomes in recent systematic reviews (21, 22). Differences in methodologic design may underlie such discrepant findings. For example, in observational studies, quantification of the nutrient exposure is challenging owing to lack of validated biomarkers of long-term intake and lack of accurate quantitative evaluation of habitual intake because of reliance on self-reported intake data such as from FFQs. In RCTs, quantification of nutrient exposure is more tightly controlled, but may be restricted to a single food or nutrient, and tracking of adherence to the intervention and blinding to the intervention can be challenging. In addition, both types of studies are prone to inherent but different biases in participant selection.

Observational epidemiologic or ecological data are often fraught with errors, such as failure to account for multiple confounders, residual confounding, selection bias, and lack of dose–response data. Furthermore, to fit the proposed analytic framework, validated indicator markers proven to be on the causal pathway between nutrient exposure and disease endpoint are essential but are not available for many chronic disease outcomes. This relation is further complicated by the following: exposures occur long before chronic disease develops; the definition of the disease or morbidity is not consistent across studies; diet may be only one of many causative factors; and the interaction of diet and disease may be modulated by physiologic state (e.g., pregnancy, physical activity, or body adiposity), ethnic profile, epigenetic factors, and genetic traits such as gene polymorphisms that alter nutrient metabolism.

DRIs for children and youth. For the ages 7 mo–18 y, ~60% of the DRI values from the initial 6 reports (2–7) were derived from extrapolation because of the paucity of primary research data specific to these age groups. Although various extrapolation models exist, no one approach was consistently used by the various nutrient panels in order to establish DRI values. As summarized in a review of extrapolation models applied to deriving nutrient-based recommendations for infants and children (23), the most commonly applied model used in the initial DRI reports involved extrapolating down from values derived for adults by using a weight or metabolic factor and adjusting for growth. In some instances, values for young children were extrapolated up from values for infants. Other limitations in setting DRIs for infants and children included a lack of nutrient-specific growth factors to adjust for extrapolations from adults, so a common factor was applied. Within an age group, variable extrapolation models (such as extrapolation up from an AI for 0–6 mo compared with down from an EAR for adults) were applied for different nutrients, leading to inconsistencies in DRI values between sequential age groupings. Given the biological and metabolic differences between children and adults, no one model of extrapolation of adult data will be valid, and thus it is critical that a primary research base be developed upon which to derive DRIs for children and youth.

Bioactive food substances. To date, nutrient-based dietary recommendations have been derived primarily for nutrients traditionally considered to be essential or conditionally essential. The effects on bodily homeostasis of such nutrients can be assessed with the use of the deficiency-repletion model, because of the rapidity and size of their effects and ease of analysis. However, bioactives do not conform to this model; effects may be small, take a long time to be evident, and may be difficult to analyze. Emerging evidence suggests that some substances in food that are not essential to life may provide benefits to health or contribute to reduction in chronic disease (24, 25). Although several nutrients hypothesized as related to chronic disease were reviewed for the DRIs, including α-carotene, lutein, zeaxanthin, ω-3 FAs, and silicon, no recommended intake related to chronic disease resulted from the review. The only nonessential nutrient for which DRI values were developed to date is fiber, and for that the AI was based on a chronic disease endpoint of cardiovascular disease risk based on serum cholesterol values. With the emergence of data on the potential benefits of bioactives to human health and perhaps chronic disease risk reduction, there has been a call to establish a framework upon which to set recommendations for the intake of nonessential food components (25, 26).

Defining an approach to setting DRI-like values for bioactive substances compared with known nutrients poses additional challenges, such as uncertainty in identifying the biologically active substances in a complex food matrix; scarcity of food composition databases with quantitative information on such substances; lack of data on requirement distributions; lack of validated intake biomarkers for bioactives; and difficulty in demonstrating acute changes in response to bioactive intake. Furthermore, comprehensive safety data are often lacking. The DRI committees consistently made the effort to go beyond depletion–repletion models in reviewing previously identified bioactive substances, but they were unable to settle on appropriate alternative models.

Although a major limitation in the existing literature is the paucity of epidemiologic and/or clinical trial data that provide evidence of a link between the habitual intake of bioactive substances and disease outcomes, some authors have set out criteria for evaluating bioactives as candidates for setting a recommended intake as a first step (25). The bioactive substances identified in such reviews for which emerging evidence appears to be the most robust were lutein, lycopene, flavanols, and ω-3 FAs (24, 25).

Framework for the UL. Although it is possible to review available data and establish an intake level at which it is unlikely that there is increased risk of adverse effects of chronic overconsumption for many nutrients, there were very little data upon which to determine a distribution in a population of consumers of increasing risk of such adverse effects in parallel to what is seen with risk of deficiency (17). A challenge for the future is to develop a model that defines a probability distribution of intake at which adverse effects might occur.

Implementation of DRIs. Because of the extensive information provided in the DRI reports, the Essential Guide to the DRIs (1) was issued to assist dietitians and other health care professionals in understanding the general uses of the multiple set of nutrient reference values. With the application of current information technology, a continuing challenge is to transfer the extensive information included in the initial DRI reports and subsequent revisions into easily obtainable formats that assist a variety of users in an improved understanding of the rationale and appropriate uses of the DRI values.

A research agenda. The knowledge gained in the development of the DRIs and the challenges as outlined above serve to set a research agenda for the additional science required to fill the knowledge gaps and to develop appropriate physiologic models that will provide a better evidence base upon which to set DRIs for all age groups in the evolution of future DRIs. Many of these research needs were presented in a workshop in 2007 (17). The emerging science must be evaluated continually in order to determine the appropriate timing for revision of the DRIs for specific nutrients or bioactive substances.

Expanded Uses of the DRIs

The DRIs may be used for assessing and planning intake for both individuals and groups (Table 1). However, the primary expanded uses of the DRIs are related to assessing and planning for intake for groups. In the past, the RDA and RNI were the only available nutritional reference standards, and although they were appropriate goals for planning intake for individuals, they were often used to assess and plan for groups. If a group's mean intake met or exceeded the RDA/RNI, it was often inferred that intake was adequate. Similarly, it was generally assumed that nutrient adequacy would be achieved by planning for a group mean intake at or above the RDA/RNI. With the new DRI framework and the identification of both an EAR and a UL, the focus is now on distributions of usual intake in a group [these distributions are estimated by adjusting for within-person variability with the use of statistical algorithms (9)]. The EAR is specifically set to be the median requirement, so, provided certain assumptions are met (9), it is possible to estimate the group prevalence of inadequacy as the proportion of the group with a usual intake below the EAR (where inadequacy is defined as not meeting the requirement for the defined indicator of adequacy). Similarly, the proportion with a usual intake above the UL estimates the proportion at potential risk of the identified adverse effect(s) of excessive intake.

Uses in dietary assessment. As a result of this new paradigm, it is now possible to determine the prevalence of nutrient adequacy/inadequacy in a group, rather than simply comparing a mean intake with the RDA. For example, the mean vitamin C intake of 14- to 18-y-old girls in NHANES 2001–2002 was 75.6 mg/d, which was above the RDA of 65 mg/d (27). Previously, it likely would have been assumed that vitamin C was not of potential concern for this group. However, 42% of teenaged girls had a usual intake below the EAR of 56 mg/d, indicating a substantial prevalence of inadequacy (27).

The DRI paradigm also allows assessment of whether an intervention or dietary practice affects or is associated with improved nutrient adequacy, whereas in the past only differences in nutrient intake could be examined. This is an important distinction, because it is possible that nutrient intake could differ without being associated with improved adequacy. This could occur if everyone had an AI irrespective of the intervention or dietary practice, or alternatively if a practice (such as supplement use) occurred primarily in those with a higher nutrient intake from food to begin with.

For example, a recent study assessed whether breakfast was associated with improved nutrient adequacy (28). Data were from ~20,000 adult participants in the Canadian Community Health Survey, and individuals were classified according to whether they skipped breakfast, consumed a breakfast containing ready-to-eat cereal, or consumed other breakfasts. Compared with those who skipped breakfast, consumption of both types of breakfast was associated with improved adequacy for vitamin A, vitamin D, calcium, and magnesium, and ready-to-eat cereal breakfast consumption was also associated with improved adequacy for vitamin C and iron. However, the mean intake of several other nutrients was also higher in one or both breakfast groups, but adequacy based on the EAR was not improved when compared with those who skipped breakfast. Thus, the higher mean intake observed in breakfast consumers did not invariably lead to improved nutrient adequacy.

Uses in dietary planning. The new framework also makes it possible to plan for nutrient adequacy (or a low prevalence of inadequacy) for groups. Traditionally, dietary planning had focused on individuals, and the planning goal used was to meet their RDA. The RDA is an appropriate target in this situation, because it is designed to exceed the requirements of almost all healthy individuals. Yet a mean intake at the RDA is not an appropriate planning goal for groups: As described above for the vitamin C intake of teenaged girls, even when a group's mean intake exceeds the RDA for that age/sex group, there can be a substantial prevalence of inadequacy. Instead, the goal of dietary planning for groups is for a usual intake distribution in which there is an acceptably low prevalence of inadequacy. For most nutrients, this can be operationalized as a low prevalence of intakes below each person's EAR.

Two different approaches have been used to plan for distributions with a low prevalence of inadequacy. The first approach, described as the Target Median Intake Approach in the IOM report on dietary planning (10), examines an existing usual intake distribution and, if required, plans to shift it by a fixed amount so the resulting prevalence of inadequacy is acceptably low. This can be illustrated with the use of the

previously described example of teenaged girls' vitamin C intake in the NHANES 2001–2002. In that group, intake at the 5th percentile was 20 mg/d (27). If planners felt that a 5% prevalence of inadequacy was acceptably low, they would plan to shift the distribution so that the 5th percentile was at the EAR for teen girls (56 mg/d). Intake would need to increase by 36 mg/d (the difference between the EAR and intake at the 5th percentile), and the Target Median Intake of the shifted distribution would thus be 36 mg/d higher than the existing median, or 100 mg/d rather than 64 mg/d. A modified version of this approach subsequently was used to identify nutrient targets for school meals (29).

The second approach was used in the development of the 2007 Canada's Food Guide (30). Food group composites, reflecting typical intake in Canada, were used initially to develop diet patterns that would lead to a mean intake at or above the RDA or AI and below the UL for each age/sex group. In the next step, the distributions of nutrient intake that would occur if a large group of individuals followed the dietary pattern for a given age/sex group were examined with the use of 500 1-d randomly generated diets that met the pattern for each age/sex group. For nutrients with an EAR, the goal was to achieve an intake distribution with a low prevalence of intake below the EAR. After the initial iteration, the dietary patterns were refined if goals were not met, the refined pattern was retested by generating another 500 random diets, and the process continued until goals were met—at least to the extent that this was feasible, to produce patterns that led to an intake distribution with a low prevalence of inadequacy that is suitable for use with groups as well as individuals.

Misuse of DRIs. Although the framework for assessing the nutrient intake of groups that use the DRIs was published 15 y ago, there are still examples in which it has been applied inappropriately (31). A frequent error has been to assume that a group mean intake at or above the EAR reflects nutrient adequacy for the group. In fact, if a group's mean intake equals the EAR, the prevalence of inadequacy would be substantial: It would likely exceed 50%, because positive skewing of a nutrient intake leads to means that are higher than medians, and the prevalence of inadequacy is 50% when median intake equals the EAR. Thus, although the EAR (rather than the RDA) is the appropriate DRI to use when assessing diets of groups, the relevant value is the proportion of the usual intake distribution that falls below the EAR, not whether mean intake meets or exceeds the EAR. Errors have also been made when assessing a group intake of nutrients that has an AI rather than an EAR; because the AI is not the mean of a distribution of requirements, it is not appropriate to assume that the proportion of intake below the AI is a measure of inadequacy (31).

More and better training is needed to disseminate appropriate uses of the DRIs in policy making at the state and local levels, and to encourage enhanced training in the translation of the DRIs into practice. An online self-help training series for policy makers, similar to the one developed for practitioners by the Dietitians of Canada (32), also might help practitioners and policy makers, many of whom are unaware of appropriate uses of the DRIs in their spheres of influence. There have been, and continue to be, misinterpretations and misapplications of the DRIs, which can do more harm than good. Sound training and sound applications of the DRIs are essential.

How the DRIs Changed Nutrition Policies

The DRIs have changed nutrition policy in several ways. First, as noted above, the EAR can be used validly to assess a group intake for the purpose of analyzing national survey data, thus leading to changes in policies related to monitoring and assessing individual and population intake and in planning federal programs that better meet target population needs (9, 10). In addition, guidance is provided on the use and interpretation of biomarkers of nutritional status, and valuable insights are also provided on the utility and interpretation of biomarkers, including determining cutoffs for adequacy or adverse effects. The DRIs are also used in policy settings in other ways by government and other bodies to identify, prioritize, plan, and evaluate public health initiatives, develop standards for feeding programs, and as the basis for food labeling information, including authoritative statements for health claims. They furnish guidance in clinical and consumer settings, and in counseling and development of nutritional materials. They also serve as important standards in new product development and reformulation by the food industry.

Space does not permit a complete listing of the extensive and positive impacts the DRIs have had on national nutrition policy over the last 15 y, but the list in **Table 4** and the examples below illustrate their importance.

Developing dietary guidance. Dietary guidelines for both the United States and Canada depend on the DRIs. In the United States, the Dietary Guidelines for Americans present the USDA food patterns for a healthy diet, which are formulated to meet the current DRIs (33, 34). Canada's Food Guide also suggests healthy food patterns that were derived with the use of the DRIs to minimize the prevalence of nutrient inadequacies (30). The DRIs also are used to identify nutrients of concern and nutrients of public health importance, and then to provide guidance on good sources of specific nutrients. The macronutrient DRIs also contribute to guidance on the healthy intake of protein, fat, and carbohydrate, as well as advice on consumption of specific types of fats, dietary fiber, and sugars. Finally, the equations used to estimate energy requirements are considered in developing guidance for both energy intake and levels of physical activity.

Monitoring and assessing dietary intake in populations. The DRIs are used to assess dietary intake in a nation's population-based nutrition survey—the NHANES–What We Eat In America in the United States (27) and the Canadian Community Health Survey in Canada (35). The DRIs have

TABLE 4 Critical health applications that depend on the DRIs in the United States and Canada[1]

Applications	Examples
Dietary guidelines	Important in formulating food-based dietary guidance, such as • US Dietary Guidelines for Americans • Canada's Food Guide • USDA Food Patterns
Nutrition monitoring	Needed to assess nutritional health on a national level • US NHANES and What We Eat in America analyses • Canadian Community Health Survey analyses
Food assistance programs	Important to guide the design of healthier federal nutrition assistance programs • School Meals, WIC, SNAP, child and adult care programs • Administration on Aging programs
Health professionals	Used for dietary counseling and education and to design healthy diets for institutions such as hospitals, long-term care facilities, and prisons
Nutrition research	Needed to study how diet can help prevent diseases and provide a frame of reference in research
Military	Used to • Ensure nutrient needs are met for armed forces • Plan healthy meals • Procure food, including military rations
Nutrition labeling	Can be used for the nutrition facts label and the supplement facts label; labels are key tools that help consumers make healthier food choices
Food and supplement industries	Used to develop healthy foods and safe supplements
Global nutrient standards	Provide a framework that is used by many other countries and international organizations when setting their own standards

[1] SNAP, Supplemental Nutrition Assistance Program; WIC, Special Supplemental Program for Women, Infants, and Children.

made it possible to make more focused, quantitative statements about groups at risk that describe not only the proportion of the population whose total dietary intake is inadequate (under their EAR) but also those who may be consuming too much (over the UL). For example, they have been used to assess folate adequacy and excess in the entire US population, as well in women in the reproductive age group and children since the fortification of wheat flour with folic acid in the mid-1990s (36, 37). Findings have led to continued monitoring of both food intake and folate biomarkers in the NHANES to ensure that adequacy was being achieved without excessive amounts being consumed and that fortification is both safe and efficacious (38, 39).

Health programs. Many large federal health programs in the United States, such as those in the Department of Veterans Affairs and other federal hospitals and nursing homes, as well as many civilian health facilities in both the United States and Canada, use the DRIs in food regulations and provisions for patients. They are also used in formulating the Dietary Guidelines for Americans (40) and Eating Well with Canada's Food Guide (41). The FDA used the DRIs to revise and update the final rule on nutrition facts labels for food products, and health officials in Canada recently undertook a similar process to update their nutrition facts labels to align with the DRIs. Healthy People 2020, the health promotion and disease prevention plan for the United States, uses population-based assessments of adequacy and excess based on the DRIs to set nutrient-related goals and objectives (42).

Food programs. The DRIs also have led to better assessment and planning of federal food programs. Several IOM reports used the DRIs to make recommendations on revisions in these programs. These included reports on the WIC food package (43–45), school meals (29, 46), and the Child and Adult Care Food Program (47). In preparing these reports, committees examined intake with the use of data from national nutrition surveys and assessed nutrient inadequacies and excesses, identified populations at risk, and set intake targets. Armed with this information, revisions to the programs to address these problems could be suggested. Federal policy makers then used these reports to revise policy and programs in school meals (48), WIC (49), and child and adult care regulations (50). Other meals programs, such as the Administration on Aging's Congregate Meals Programs for Older Americans, deserve to be studied with the use of the same methodology. In Canada, DRI reports have been used to devise nutritional recommendations for healthy infants (51, 52). Benefit levels of programs such as Food Stamp allotments (for the Supplemental Nutrition Assistance Program) are set with the use of the DRIs. They are also used as nutritional goals for the Thrifty Food Plan, a low-cost food plan for low-income individuals who are enrolled in the Supplemental Nutrition Assistance Program (53).

Military. The US Department of Defense (DoD) begins planning its food programs with the DRIs, and then, after taking into account any special considerations for certain nutrients that apply more specifically to warfighters, issues AR40–25, Military Dietary Reference Intakes (MDRIs). The MDRIs are used for meal formulations and in many other ways in the armed services. The MDRIs have been the major impetus for changes in policy that affect several DoD food programs and serve as the basis for the DoD's Master Menu that directs military feeding in garrison and in the field, and in development of special rations, such as

assault rations, combat field feeding systems, long-life ration packets, a new generation of a survival packet, other calorie-dense rations, and rations for short-term, high-intensity combat operations.

For many years, FNB committees have assisted DoD in tailoring the DRIs to the special problems and conditions faced by the military in assessing relevant mineral requirements, protein and amino acid requirements, dietary supplement use, associations between antioxidants and oxidative stress, and fluid replacement and heat stress. One example is a report on nutrient composition of assault rations for high-energy combat operations—considering space, stability, weight, and other constraints that ultimately served as the basis of the First Strike Ration that was developed and now is used by the military (54). Reports resulting from these efforts are valuable references not only for the military but also for others who deal with individuals who have very active and physically demanding jobs.

Policy impacts and challenges. The examples above illustrate how the DRIs impact many health applications, as well as the remarkably swift translation of the DRIs into federal policies and programs. The DRI concepts and values also have had a potent role in policy in other countries, including several in Europe, Asia, and South America.

Many research questions relevant to the national nutrition policy applications of the DRIs have emerged, and these questions need attention (17). Perhaps the greatest challenge is to make sure that government nutrition policy makers understand the DRIs and their importance to policy and programs. It is vitally important that appropriate applications of the DRIs be put in place to better leverage resources in nutrition policy. Decisions on the way forward are needed by the respective governments to keep volunteers engaged in updating and refining the DRI process to avoid losing momentum.

Current and Projected Development of the DRIs

DRIs have been set for many nutrients, but most of them have not been reviewed recently. Although the DRIs for calcium and vitamin D were revised in 2011 (8), other vitamin and mineral DRIs were last reviewed in 1997–2001 (2–5). DRIs for macronutrients, energy, and electrolytes have not been reviewed since 2002 or 2004 (6, 7). The DRI reports on appropriate uses in dietary assessment [released in 2000 (9)] and dietary planning [released in 2003 (10)] also need updates. In the interim, as shown in Table 3, many concerns about the current DRIs have been identified.

Updating the current DRIs

No updates to specific DRIs are currently planned, and no DRI reviews by the FNB are currently in place, because the process is dependent on external funding. From the scientific and policy standpoints, it is unfortunate that the update process is not moving forward, because the DRIs have served as a potent influence on national nutrition policy, making it more rational, measurable, assessable, and defensible. However, challenges remain. The greatest of these are funding and political will. Because the DRIs have such an impact on national nutrition policy, they must be based on the best possible and most up-to-date science. It is penny wise and pound foolish to neglect to fund timely and periodic updates to the DRIs themselves and to continue to fund the federal and other programs that depend upon them and may need alteration. As of this writing, funding for future revisions by the US and Canadian governments appears to be unavailable, and there is no consensus about how to move forward. Two approaches have been suggested: A nomination process to be overseen by the US and Canadian governments, and a core review process to be developed by the FNB.

Nomination process. The US and Canadian governments have established ongoing DRI committees that include representatives from multiple agencies within the USDA and the NIH in the United States, and several agencies within Health Canada. These committees have worked together to establish a nomination process to identify nutrients with DRIs that need to be updated. As noted on the website (55), the nomination process has the following features: It applies only to nutrients that currently have a DRI; input from all interested parties is welcome, including federal and nonfederal individuals and organizations; the government committee will prioritize requests and determine which (if any) to fund; priority is based on evidence of significant, new, and relevant data; and submissions must include a cover letter and a literature review.

Nominations were accepted from May–July 2013 for 16 nutrients. From these, 4 nutrients/groups were selected: ω-3 FAs, sodium, magnesium, and vitamin E. However, the agencies decided that a workshop on using chronic disease endpoints for DRIs was needed before nutrient reviews could be undertaken. On 10–11 March 2015, a workshop on Options for Consideration of Chronic Disease Endpoints for DRIs, organized by federal DRI committees in the United States and Canada, was held at the NIH. A 12-member panel of academic scientists and others was convened and asked to write a report summarizing the results of the workshop (56).

Core review process. The FNB has considered a process in which a core committee would be responsible for the periodic review of all DRI values, with the goal of ensuring that DRI values remain current. The committee would begin with nutrients with the oldest DRIs, and decide if *1*) values do not need to be changed; *2*) minor changes are needed; or *3*) a deeper systematic review is needed (via the federal nomination process). Thus, the core committee would interface with the proposed government nomination process for major updates. This would be a multiyear process, reviewing several nutrients per year so that all are reviewed on a fixed cycle.

A possible process for each nutrient has also been discussed by a DRI working group of the FNB. The steps would

include the following: *1*) Decide on an appropriate analytic framework and determine the clinical and biochemical markers of an AI of the nutrient(s) of interest; *2*) conduct literature searches with the use of relevant keywords; *3*) review abstracts and papers; *4*) consult experts on the nutrient (s) of interest; and *5*) decide whether the nutrient should be submitted to the federal nomination process.

To illustrate this process, the FNB working group undertook a literature scan for thiamin, a nutrient with DRIs that have not been reviewed since 1998. The literature scan identified 12,154 abstracts on the first pass, but the number was reduced to 933 when the search was limited to clinical trials or prospective studies. After examining the abstracts, the set was further reduced to ~70 abstracts of possible relevance to setting DRIs. Considering such an example was helpful because it identified a potential process for other nutrients. It also illustrated that the literature scan is not a trivial task, even for a nutrient with relatively little new data. More details on the literature scans for thiamin as well as phosphorus will be presented in a published paper. It appears that the use of a core DRI committee has the potential to maintain scientific rigor while substantially reducing the costs of updating the DRIs. Such an approach would allow the FNB to continue the task of providing nutrient standards as it has done successfully for ~70 y.

Increasing the visibility of the DRIs

To emphasize that current DRIs are key components of nutrition monitoring and the development of many types of nutrition guidance and programs, the FNB has developed a list of the crucial applications of the DRIs (Table 4). This information has been compiled into a brochure on the importance of DRIs, and it is now available (57). By clearly describing the multiple uses of the DRIs, it is hoped that the brochure can help to obtain more stable funding for this activity.

Coordinating DRIs and dietary guidelines

As noted earlier, the Dietary Guidelines depend on the DRIs, so it is important to coordinate their updates. A division of expertise and effort should be considered: a DRI core committee to focus on updating and extending nutrient standards for the United States and Canada, and the Dietary Guidelines Advisory Committee to focus on applying these standards to food choices and dietary patterns in the United States. Both committees would conduct systematic evidence-based reviews, as needed, to examine relations to health. However, funding for DRI reviews remains problematic. Legislation to mandate regular updates to DRIs may be needed, perhaps on a 10 y cycle. Coordination of DRI reviews with the Dietary Guidelines cycles might increase efficiency.

Harmonizing global nutrient standards: A vision for the future of the DRIs

In 2007, a report from an international group of scientists proposed a process for international harmonization of approaches for developing nutrient-based dietary standards (58). This process has not yet been implemented, but there are many reasons to move it forward. A harmonized model for setting nutrient standards could ensure a consistent approach, and collaboration on systematic reviews could ensure the same scientific basis for standards. Although agreement on the numeric values for the EARs and ULs would yield the greatest time and resource savings, this step should be undertaken only after there is agreement on methodology. Although a global process should be possible for setting nutrient standards, applying these standards to food choices and dietary patterns almost certainly will remain a country-specific activity.

There are many advantages to a global approach. It would improve objectivity and transparency of values, and provide a common basis for groups of experts to use throughout the process of setting values. It would also permit developing countries with limited resources to modify their existing reference values in keeping with new science. Nutrition policies based on nutrient standards also could be more consistent across countries. Other advantages of a global approach include less redundancy and a more efficient use of professional time and resources. Limited funds could be pooled so that there is no large burden on any specific country/region for updating values. Furthermore, this approach might lead to an increased understanding and a more appropriate application of values. Finally, a timely update process could prevent the setting of inappropriate policies that are based on out-of-date standards. The FNB, in partnership with the FAO and WHO, is seeking funding for a workshop on Planned Approaches to Global Harmonization of Nutrient Intake Standards, with the goal of extending the work proposed in the 2007 report.

Conclusions

After 50 y of RDAs and RNIs, the DRIs have brought a new paradigm to planning and assessing nutrient intake in the United States and Canada in the last 20 y. Many applications, including national food guidance in Canada and the United States, depend on the most accurate estimates of DRIs possible. It has been a long road indeed leading to the DRIs, but the road must not be a dead end. Monetary resources and political will must be made available to maintain the DRI edifice and the momentum, and to keep the DRI values up to date.

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