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RDA for Indians-what more do we need, and do these fit requirements?

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Introduction

"What is the daily requirement of a nutrient?" The appropriate responses to this question would be, "Is it for an individual or a population?" and "I cannot know this, unless I can actually measure the requirement". The concept of a daily requirement of nutrients is important in diagnostic and prescriptive applications, both at the individual/clinical level, and at the population level. Different requirement values are used for individuals and for populations, and these are often used incorrectly. For example, evaluations of the nutrient intakes of a population are made against the recommended daily allowance. This is wrong in many ways. Even if the population is of the same age and gender, there is an inherent physiological variability in their requirement, and statistical concepts around the definition of a nutrient requirement have to be considered.

Therefore, to return to the question, in order to accurately define the requirement, it must actually be measured experimentally. We know this is difficult if not impossible outside a clinical physiology setting. It is, however, possible to define a requirement which can be used to assess the probability of risk of inadequate intake, in an individual or in a population. This framework has led to different numerical constructs that define the requirements for individuals and populations. While the ICMR has brought out an excellent report on nutrient requirements in India[1], the importance of a framework is underscored by the fact that the single reference nutrient intake that has been used in this report is the "recommended daily intake" or the RDA. However, as will be discussed below, this is conceptually the intake at which the risk of deficiency in the individual is minimal. It does not apply to populations.

Do the defined nutrient requirements consider interactions with other nutrients or the environment?

It might seem simplistic and reductionist to consider the daily requirement of a nutrient on its own; nutrients interact with each other and with the physiological state. The idea is to define daily requirements in a much more integrated manner. This is a difficult task, given the number of potential interactions that exist, and the difficulty of quantifying these in different physiological states. At present, allowances, or overages, are made for such interactions, but this is only a start.

This is particularly relevant to the need to define specific (single) nutrient deficiencies and provide single nutrient remedies through supplementation and fortification. Mixed results are inevitable and, in general, one may not be far from the truth if one were to conclude that single-nutrient remedies might not work as well as required. The framework linking a specific nutrient to a specific outcome is a good start to defining risk, but if one does not consider the multiple interactions that occur when food is prepared and eaten, or within the body with multiple deficiencies, or with the environment when infections occur, it is quite possible that designed interventions will fail. The example of iron intake and anaemia is instructive, as discussed later. To a pragmatic extent, the clinical paradigm linking a specific nutrient deficiency to a specific clinical outcome is well known and understood. Where deficiencies are severe enough to result in symptoms or signs, supplements or therapeutic doses work very well to ameliorate the clinical outcome of such deficiencies. However, in public health, many deficiencies are mild, and it is very likely that single-nutrient approaches will not work as well as one desires, simply because the influence of other interactions now comes to the fore. Giving ever larger supplements of a nutrient is also unlikely to work: a balanced approach, anchored on real food is essential if any success is to be expected.

Is there a limit to how much of a nutrient should be eaten in a day?

Of course, some nutrients will always be deficient or in excess in specific diets, and there is always a need to fine-tune approaches through food selection or even fortification. Too much of a good

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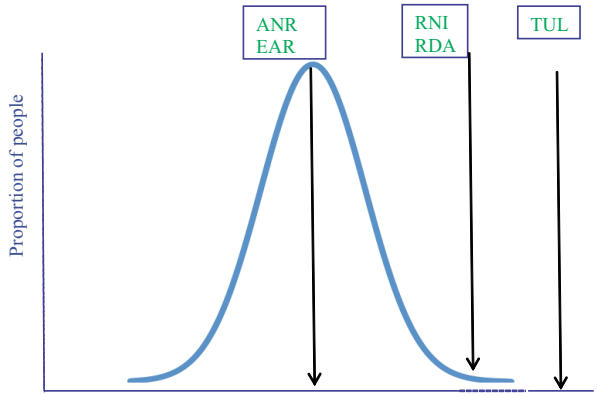
thing can be bad. Therefore, there is a need to define the maximum of a nutrient an individual (or population) should safely eat. Once again, this is difficult to define precisely, for reasons similar to those stated above. However, using a similar risk quantifying approach, one can work out and define an upper limit of the requirement at which the risk of excessive intake begins to appear. This is particularly important for supplementation or fortification programs in public health. In addition, given the plethora of food products for ready consumption, it is important from a regulatory perspective. At present, the fortification of ready-to-eat foods is limited to less than 1 RDA, and this is because there is no nutrient intake at which safety is defined. Unless the upper limit of safe intake is defined, it is difficult to judge the potential adverse effects of eating too much of a fortified food on the one hand and the adequacy of fortification on the other. This is also discussed below.

Can we define an ideal diet through its nutrient density?

The nutrient density of a diet is a concept that is readily accessible and understandable, but an index that brings these together is important. Such indices are those that are based on the food intake, and they need to be tested against outcomes. It is also a cautionary tale for proponents of a single-nutrient fortification approach. It is more than likely that where deficiency of a particular nutrient is found, multiple nutrients will be deficient in the diet. In other words, the definition of nutrient requirements must not stray too far from the definition of an adequate diet. The cereal-dominated diets in India are a good example of how diets may be deficient in a number of nutrients simultaneously.

Figure 1. Distribution of the requirements of a theoretical nutrient in a population, showing ANR/EAR and RNI/RDA. The TUL is also depicted as an intake in excess. The dashed line on the X-axis depicts a variable distance between the RNI/RDA and the TUL for different nutrients.



It is also relevant to those who wish to limit their energy intake through 'eating less food'. As with aging, where the energy requirements fall, an energy-restricted diet is particularly prone to becoming deficient in nutrients, and its quality becomes paramount. This is also discussed below.

A framework for nutrient requirements

Several countries recommend nutrient intakes for their populations. These are used to plan and evaluate the nutrient intakes of healthy

Table 1 Definition of terms used in the framework of nutrient requirements

· *Average Nutrient Requirement (ANR)* · *Estimated Average Requirement (EAR)*	Refers to the average daily nutrient intake level estimated to meet the requirements of half of the healthy indviduals in a particular life stage and gender group. It is used primarily to evaluate populations or groups.
· *Recommended Nutrient Intake (RNI)* · *Recommended Dietary Allowance (RDA)*	Refers to the daily dietary nutrient intake level that is sufficient to meet the nutrient requirements of nearly all (97-98 percent) healthy individuals in a particular life stage and gender group. This is derived from the ANR/EAR as the mean plus 2 standard deviations (SD) of the distribution of requirements. The term is used to primarily evaluate individual diets. *The RDA is inappropriate for dietary assessment of groups as it is the intake level that exceeds the requirement of a large proportion of individuals within the group.*
· *Upper Nutrient Level (UNL)* · *Tolerable Upper Level (TUL)*	Refers to 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. As intake increases above the UL, the risk of adverse effects will increase.
· *Adequate Intake (AI)* · *Safe Intake*	These values are used when ANR or RDA cannot be determined. The Safe intake or AI is 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.
· *Lower reference nutrient intake (LRNI)* · *Lower threshold intake (LTI)*	Refers to a value derived from the ANR/EAR and is calculated as the ANR/EAR minus 2 SD of the distribution of requirements. This value is sufficient to meet the needs of the bottom 2% of individuals. However countries have used a different cut off such as 5% or 10% to evaluate nutrient insufficiency, although the concern is that these values would set a very low expectation of the individual nutrient intake adequacy level.

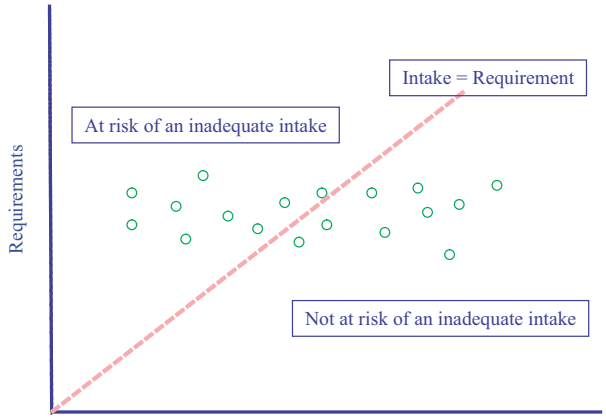
people. Nutritional policies, food regulations and nutritional programs are based on these nutrient intake recommendations[2]. The recommended values differ from country to country and could range from a single value for a population group (as in the ICMR report for India[1]), to four different values that define a 'lower reference intake', an 'average requirement', a 'recommended intake' for individuals from a specific population, and an 'upper tolerable intake'[1,2].

In 2007, the United Nations University's Food and Nutrition Program, in collaboration with the Food and Agriculture Organization (FAO), the World Health Organization (WHO), and UNICEF, attempted to harmonize the recommendations used across several countries, and coined the term Nutrient Intake Values (NIV), using primary data from several countries. These were primarily, Dietary Reference Values (DRV, UK), Nutrient Reference Values (NRV, Australia, New Zealand), Reference Values for nutrient supply (Germany, Austria, Switzerland), and Dietary Reference Intakes (DRI, USA, Canada)[2,3]. The approach to describing the average requirement and the recommended intake are shown in Figure 1.

Two of the NIV's were recommended for comparability across all countries for specific life stages and genders: average nutrient requirement (ANR) which is equivalent to the Estimated Average Requirement (EAR[4]) and Upper Nutrient Level (UNL) equivalent of the Tolerable Upper Limit (TUL[4]). The other values, like the Reference Nutrient Intake (RNI)/ Recommended Dietary Allowance (RDA)/ Recommended Dietary Intake (RDI), which are very similar to each other, and the Lower Reference Nutrient Intake (LRNI), were derived values from the two recommended NIVs. The IOM suggested that, although their recommendations were on the basis of dietary intakes in the United States and Canada, their values could be adapted to other populations by adjusting for nutrient bioavailability[4]. Each of these terms is defined in Table 1. An additional term that is used is the Acceptable Macronutrient Distribution Ranges (AMDR). The AMDR is a range of macronutrient intakes that is associated with a reduced risk of chronic diseases but at the same time provides adequate intakes of essential nutrients. It is usually expressed as a percentage of energy, with lower and upper limits. In the US and Canada, the AMDRs refer to appropriate ranges of usual intakes of individuals, whereas the WHO standards are mean intake goals for the population. Based on the latter, the mean intake goal for total fat intake is 15% to 30% of the energy intake, and implies that it is acceptable for half of the individuals in a population to have intakes below 15%[2,5].

The key measurements within this framework, as defined above, are that of the ANR/EAR and its variance, and that of the TUL. The ANR/EAR is ideally directly measured experimentally. This has been done for some nutrients, for example, energy, protein and amino acids[6,7]. However, this also has to be performed at different ages, since growth imposes its own demand on daily nutrient intake, while aging has its unique impact on the requirement. If the measurement is performed easily and non-invasively, then it is ideal for use across ages. Unfortunately, many of these measurements require some degree of invasive procedures, meaning that the measurement is not possible in vulnerable populations; they call for a careful selection of subjects, and controlled settings, meaning that these are 'laboratory or perfect conditions' measurements, and not 'real world' measurements. The use of stable isotope technology has been key to the development of less invasive measurements, such as the double-labeled water method for the measurement of energy expenditure[7], and the indicator amino acid oxidation method for indispensable amino acid requirements[8]. The key measurements used in the framework of nutrient requirements are the mean of the requirements or the ANR/EAR, and the distribution or variance of

Figure 2. Theoretical scatter plot of nutrient intake vs requirement. The line of identity refers to a situation where nutrient intake matches the requirement.



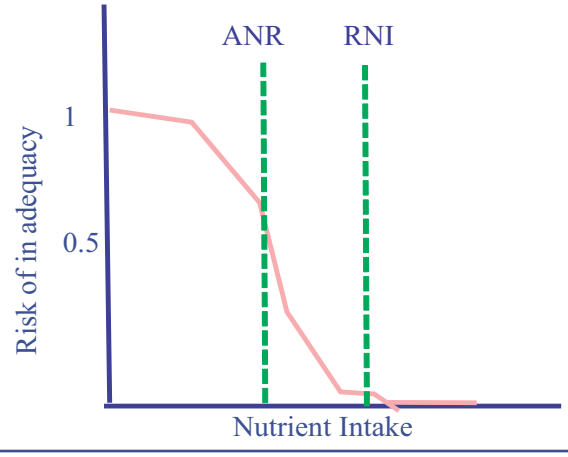
the requirements, which yields a standard deviation (SD), which is then used to calculate the RNI/RDA. Note that a normal distribution is required for this method; if the distribution is not normal, then it must be normalized before the SD is used. This is relevant for some nutrient requirements, notably protein and iron.

What if the ANR/EAR cannot be experimentally measured? Another approach, in these circumstances, is to deconstruct the total daily requirement into a set of compartments or factors that can be added up. For example, energy requirements are calculated as the sum of the basal requirement and the requirement for activity and thermogenesis[7]. This requires assumptions to be made of the mean of each factor, and is called the factorial method. The distribution of the requirement is either assumed from observations in the literature, or calculated indirectly from the variability of body size or growth, which is a key 'factor' in determining the daily requirement.

The conceptual basis for calculating the risk of inadequacy

An individual has inadequate intake of a specific nutrient when the intake falls short of the body's requirement of that nutrient. If the distribution of requirements in a population were known (and the individual could be reasonably said to be representative of this population), then the ANR/EAR and the RNI/RDA will be known. Since the RNI is the sum of the ANR and 2 SD, it means that if an individual consumes the recommended intake, his/her chances of

Figure 3. Conceptual figure of risk of inadequate intake plotted against nutrient intake. At an intake that equals the ANR/EAR, 50% of the population is theoretically at risk of an inadequate intake.



being at risk of inadequacy of intake is <2.5%.

In a population, the risk of inadequacy translates to the proportion of people whose usual intake of a nutrient does not meet the requirement. The risk of an inadequate intake in the population can be easily calculated if population-level data on usual intakes and actual requirements are available (which is usually not the case). If these data were available, a critical requirement of risk calculation is that the intake distribution does not correlate with the requirement distribution (Figure 2). As can be seen from this theoretical figure, the nutrient intakes of a population are quite variable and have a large range. The tightly regulated nutrient requirements, as expected in biological systems, are represented on the Y-axis. The result is that the scatter does not lie on the line of identity, but is flat. Nevertheless, one could now identify the proportion of the population that was eating less than their requirement, as those to the left of the line of identity[9].

However, obtaining such data (on the intake and requirements of a population) is impractical. Therefore statistical approximations are used to assess the risk of an inadequate intake. One such method is the probability approach where a continuous risk curve of probability that any intake is inadequate is plotted against the intake value. In this plot, the lower levels of intake will have a probability of inadequacy that is close to 100%, and this declines with increasing intakes, such that higher levels of intake have a 0% probability of an inadequate intake (Figure 3). By plotting the usual intake distribution against this probability plot, the proportion with the probability of an inadequate intake can be determined.

The 'EAR cut point method' is a simplification of the probability method in which the proportion of the population with an intake lower than the EAR for the nutrient, are considered to be 'at risk for an inadequate intake'. A word of caution is needed for this method, simple as it seems, since the following assumptions are made for the EAR cut point method: a) the nutrient intakes and requirements are independent, b) the requirement distribution is symmetrical around the EAR, c) the variance in intakes is larger than the variance of requirements, d) the true prevalence of inadequacy in the population is no smaller than 8-10% or no larger than 90-92%.

For nutrients whose distributions violate these assumptions, such as iron, adjustments are made[9]. Another example is that of the energy requirement, which is closely related to the intake. This violates the assumption of independence between the intake and requirement, and consequently for energy, a separate term, the Estimated Energy Requirement (EER) is used; there is no RNI or RDA for the energy requirement, since the latter would grossly overestimate the requirement.

Table 2 Tolerable Upper Intake Levels (TULs) of selected vitamins and minerals.

Nutrient	1-3 years	4-8 years	9-13 years	19-70 years
Vitamins				
Vitamin A (µg RE)[a]	600	900	1700	3000
Vitamin C (mg)	400	650	1200	1000
Niacin (Vitamin B_3) (mg NE)	10	15	20	35
Vitamin B_6 (mg)	30	40	60	100
Folic Acid (µg DFE)[b]	300	400	600	1000
Minerals				
Iron (mg)	40	40	40	45
Zinc (mg)	7	12	23	45
Calcium (mg)	2500	2500	2500	3000
Phosphorous (mg)	3000	3000	4000	4000
Iodine (µg)	200	300	600	1100

Adapted from "Guidelines on food fortification with micronutrients", WHO/FAO 2006.
[a] Refers to preformed vitamin A only (i.e. esters of retinol). 1 µg RE= 3.33 IU vitamin A.
[b] Refers to folic acid derived from fortified foods, or supplemental folic acid

Tolerable Upper Limit (TUL)

The TUL is the maximum level of habitual intake from all sources of a nutrient or related substance judged to be unlikely to lead to adverse health effects in humans[10]. An adverse effect is a change in morphology, physiology, growth, development, reproduction or lifespan of an organism, system, or (sub) population that results in an impairment of functional capacity, an impairment of capacity to compensate for additional stress, or an increase in susceptibility to other influences. The potential risk of adverse effects increases after the intake increases above the UL The TUL applies to chronic daily use and it is important to first assess the characteristics of the individual or group, the source of the nutrient, the physiological state of the individual and the duration of sustained high intakes. The bioavailability of a nutrient, which is its accessibility to normal metabolic and physiological processes, also plays a role in the nature and severity of adverse effects at excessive intakes. However, in some cases, the unabsorbed nutrient may also have effects on the lower parts of the intestine. This is particularly relevant for iron, in which the unabsorbed iron may have effects on the intestinal microbiome. The most appropriate approach is to establish the TUL for age/gender/life stage sub-populations, since adverse effects of nutrients are influenced by growth and physiological stages.

The increased availability and consumption of fortified foods and food supplements has sparked concerns about excessive intake of nutrients. It is important to assess the safety of fortification by comparing eventual micronutrient intakes with the TUL. High levels of micronutrient additions should be avoided even if a micronutrient has no recommended TUL, particularly if there is no evidence of derived benefit from levels of intake in excess of the RNI. Equally, if there is evidence of poor bioavailability, or evidence of benefit at intakes beyond the RDA level, as well as a safe distance between the RNI/RDA and the TUL, there is no reason why fortification beyond the RNI/RDA should not be considered. At present, in India, fortification of foods and food products is limited to 1 RNI/RDA, one reason is that India has no defined TUL for nutrients. The TUL for certain vitamins and minerals, from other countries, are presented in Table 2.

Risk assessment is a systematic means of evaluating the probability of occurrence of adverse health effects in humans from an excess exposure to an environmental agent[10]. Risk assessment has four stages, including hazard identification, hazard characterisation (through dose-response assessment), exposure assessment and risk characterisation. The risk assessment process needs to be rigorous and transparent, particularly with regard to the paucity of the data in human populations. Almost all of the risk assessments have an inherent uncertainty and variability and identifying and accounting for these is an essential part of the data analysis, while identifying and characterizing the hazard. Various national and international advisory bodies, have used the same data, but arrived at different risk assessments due to the different judgments made about identifying adverse effects, the nature of uncertainties in the assessment, and in matching the upper levels with exposure assessments and dietary reference values. Since the establishment of different upper levels for different nationalities is a source of

confusion in public health policy and practice, a collaborative development of the model for establishing upper levels of intake for nutrients and related substances was proposed by a Joint Task Force of the World Health Organization and the Food and Agriculture Organization[10].

There are many terms that are used in this context, such as the no-observed- adverse-effect level (NOAEL), lowest-observed- adverse-effect level (LOAEL) and uncertainty factor (UF). NOAEL is the highest intake of a nutrient at which no adverse effects have been observed in the individuals or groups. LOAEL is the lowest intake at which an adverse event has been identified. UFs are applied to address both the gaps in data and incomplete knowledge. There are many scientific uncertainties associated with extrapolating data to the general population, from the observed values and several judgements need to be made in deriving uncertainty factors for each nutrient. The individual UFs are combined together to arrive at a composite UF for the nutrient. The UFs are lower with data of high quality and when adverse effects are mild and reversible. The TUL of a nutrient is normally derived by dividing the NOAEL (or LOAEL) by the composite UF[11].

The estimation methods for the LOAEL, NOAEL, and the ADI values are based on a well-accepted procedure. The LOAEL is first determined, based on available data from animal studies. One level below that is the NOAEL, and a hundredth of the NOAEL is the ADI . In case adverse event data from human studies are used, the ADI is usually found to be about one third of the LOAEL .In this framework, the TUL is basically the ADI, and refers to the quantity of nutrient coming from all dietary and supplementary sources in a day.

From the viewpoint of fortification, or the supply of extra nutrient in the diet, it is clear that as the nutrient intake progresses above the RNI/RDA, it could continue to be of benefit (this has to be judged based on the evidence available). However, this progressive benefit will occur only in a small proportion of the population. The key point to consider here is not the potential incremental benefit to a smaller group, but the possibility of harm to the general population. Usually, there will be no harm done until the intake crosses the ADI by a factor of several-fold, but this has to be determined for all proposed fortificants. For regulatory purposes, it is the margin of safety that has to be determined, and this is the number of multiples of the nutrient intake above the ADI that can be taken safely. This window is narrow for some nutrients and wide for many. A careful determination needs to be made in different populations, since, albeit unlikely, the role of genetics and the environment in altering the TUL cannot be dismissed. This exercise is sorely needed in India. Public concerns about adverse events with nutrient supplementation, and the regulation around this process, need to be informed with appropriate procedural notifications.

Optimal requirements vs. minimum requirements

When obtained experimentally, nutrient requirements are specific to the conditions in which they were studied. Typically these are in 'clean' labs, where subjects are chosen for their good clinical health, and given prophylactic medication (for example, deworming for iron requirement studies). However, this is not the real world, where unsanitary conditions, and sub-clinical infections and parasites may change a physiological need for a nutrient. Equally, it is possible that a successful 'adaptation' to a low nutrient requirement may be at play, considering that it is poor people with poor quality diets who live in poor environments.

In respect to protein, this has become an issue of interest in the recent past. Protein quality is usually judged by a chemical composition that matches the amino acid requirement, but there is now evidence the digestibility of these amino acids varies greatly in the small intestine, meaning that a simple chemical score would need to be corrected for small-intestinal, or ileal digestibility[12] (an equivalent term would be bioavailability). Protein quality is important, since in resource-limited settings poor dietary quality has marked negative impact on health, especially during the sensitive periods of pregnancy and the first two years of life, during which stunting, poor development and increased risk of later disease develop. Protein quality is often poor due to high amounts of low-quality cereals and little animal food.

The requirement of protein and amino acids has also received attention in terms of requirements for many functions in the body other than the maintenance of the body protein mass. These functions could range from regulation of body composition and bone health, to gastrointestinal function, to glucose homeostasis, to cell signaling, and satiety[13]. It might be stated that the ANR/EAR and the RNI/RDA are minimum requirements, measured using only one paradigm of protein homeostasis. Research in these areas is limited, but is still worth noting that the requirement framework does not take these considerations into account, and uses only a simple daily nutrient balance measurement as an indicator of homeostasis. At most, overages, or 'allowances', are added for infections or illnesses, as in the case of protein[14].

An example: the iron requirement and the risks of inadequate and excessive intake

In instances where the distribution of intakes and requirements are asymmetrical as in the case of iron, particularly in menstruating women and adolescents, the full probability approach needs to be used to assess the inadequacy of intake[4,15,16]. This method determines the probability of inadequacy of usual intake for each person in the group; the mean of the individual probabilities is then obtained in order to estimate prevalence of inadequacy. The caveats to using this approach are as defined above.

The iron requirement has been calculated using factorial modeling, where the factors include the basal iron losses, menstrual losses, fetal requirements during pregnancy, increased requirements during growth, and/or increased tissue storage[17]. The variability of the basal loss is assumed to be, for example, 15%, but the loss due to menstruation is highly skewed, such that a median value with the 95th percentile is described[18]. The sum of these values, along with the 95th percentile leads to an absolute median physiological requirement, in females >18y, of 1.46 mg/day, with a 95th percentile of 2.94 mg/day[18]. This median value is close to the ICMR 'RDA' figure of 1.5 mg/day in non-pregnant, non-lactating women[1]. However, the latter report does not identify the 95th percentile, but uses the median value (analogous to the RNA/EAR) to identify a 'safe' numerical physiological requirement.

The next step for defining the dietary iron requirement is to assume a value for the bioavailability of iron in the diet. Using a value of 8%, the ICMR RDA arrived at a requirement of 21 mg/day[1]. The FAO report on the other hand, used several different bioavailability figures (5-15%), which were applied on the 95th percentile value, to arrive at RDA requirements of 58.8-19.6 mg/day, respectively[18]. The ICMR 'RDA'[1] (based on the median value) sits at the lower end of this range. In effect, the Indian 'RDA' actually reports the median requirement or the equivalent of the ANR/EAR, even though it is called the RDA[1].

However, the high value of the FAO-derived RDA, assuming 5% bioavailability, presents a problem when viewed against the TUL that

Table 3 Risk of inadequacy of iron intake in different age groups in rural India, according to their iron intake[19] and median requirement[1]

Age group (years)	Iron (per day)		
	EAR/RNI (mg)	Intake (mg)	Risk of deficiency (%)
1-3	9	5.7	74
4-6	13	8.6	76
7- 9	16	10.2	79
10 -12 boys	21	12.0	84
10 – 12 girls	27	11.5	97
13 – 15 boys*	32	13.3	99
13 – 15 girls*	27	13.0	95
16 – 17 boys	28	16.4	87
16 – 17 girls	26	13.5	93

*: These requirements[1] are probably in error – girls should have a higher requirement than boys

Table 4 Risk of an excessive intake of iron intake in different states (rural) of India, according to their iron intake[19], an assumed increase in iron intake of 10 mg/day, and an assumed TUL of 45 mg/day.

State	Usual Iron Intake mg/day	Iron Density mg/1000 Kcal	Fortified % Risk of >TUL*
Kerala	9	7	0.3
Tamil Nadu	8.5	5	0.2
Karnataka	11.5	6	1.4
Andhra Pradesh	7	4	0
Maharashtra	11.5	8	1.4
Gujarat	17	9	9.1
Madhya Pradesh	18.5	10	12.3
Orissa	13.5	7	3.4
West Bengal	11	8	1.1
Uttar Pradesh	16.5	9	8.1

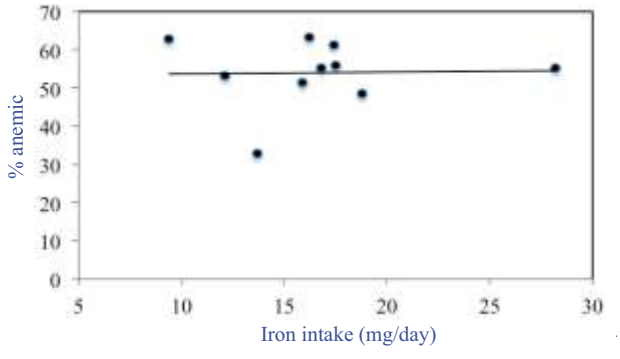
*: Refers to the proportion of population at risk of an intake in excess of the TUL

has been defined for iron, which is ~45 mg/day[4,19]. This specific RDA value is in excess of the TUL, but it must be remembered that the risk of deficiency for populations is judged on ANR/EAR and not on the RDA. The RDA is used only for individuals, and ensures that the risk of inadequacy at that intake is less than 2.5%. Clinical and nutritional judgment is required before prescribing such an intake for an individual. The TUL that has been defined is based on gastric symptoms that were reported at that intake. In India, the TUL has not yet been defined, and this lacuna is very significant, as discussed below.

To assess the risk of inadequacy, nutrient intakes need to be described carefully and the intake distribution has to be adjusted on the basis of at least two nonconsecutive days of dietary recalls to obtain the usual intake distribution. The intake distribution is divided into several intervals and the Z value for each interval, based on the standard deviation values of the requirement distribution, is estimated[17]. The probability of deficient intake corresponds to that of the Z value in the standard normal distribution. The Z value is calculated as: l n(available iron - basal losses) – l n[(mean menstrual losses) / l n(SD menstrual losses)]

where the 'available iron' is the median value of dietary iron intake for an interval. The major steps involved are a) the number of individuals with intakes within each interval is determined, b) the product of this number with the appropriate probability for the interval is calculated to get the number of individuals in each interval who are likely to have intakes below their own individual requirements, and c) the numbers are summed and expressed as a percentage of the total population. Based on this calculation, applied to intake data from the NNMB for rural populations[20], Table 3 describes the risk of an inadequate iron intake in different age groups. For this, the median requirement is used, which is reported as the RDA in the ICMR requirements report[1]. For measuring population risk of deficiency, the median is the right value to use. Not surprisingly, the risk of inadequacy is very high. It is interesting to note that if the reported intakes were increased by about 10 mg/day (as in a successful fortification program), the risk of inadequacy would fall, but would still be greater than 50-60% in all age groups. This is because the iron requirement is high, based on a low bioavailability.

Figure 4. Shows a plot of intakes versus anaemia prevalence in different states in India (reference 23).



It is then possible to consider fortifying the diet with iron to a greater extent. Indeed, this is one of the strategies proposed in public health nutrition. However, given the skewed nature of the intake, it is alsoworth considering the risk of excessive intake of iron, with this level of fortification. Table 4 shows this risk for rural adult women, based on data reported in NNMB[20], now described State-wise, if their diets were to be fortified with an additional 10 mg of iron per day. While the risk of deficiency falls to about 60%, the risk of excess intake begins to appear, reaching about 10% in States where the reported iron intake was reasonable to begin with. As one fortifies more enthusiastically, the risk of an excessive intake will increase.

One could consider the risk for exceeding the TUL for iron as being somewhat acceptable, if judged only by the adverse GI symptoms. However, it has to be borne in mind that the unabsorbed iron that reaches the lower intestine, has its own adverse effects on the microbiome. At least two studies in Africa have shown that iron fortification for 4-6 months in children, and iron supplementation in infants, resulted in an adverse gut bacteria profile and gut inflammation[21,22]. The long-term consequences of this are unknown.

Clearly, a public health strategy needs to consider a balance of risks between deficiency and excess intake of iron. One illuminating finding emerges from an analysis of daily iron intake and anaemia prevalence in different States in India[23]. In Figure 4 (adapted from ref 23), it is clear that anaemia prevalence among women appears to be

high and static, regardless of the iron intake. This suggests that an important strategy to improve body iron status would be to improve the absorption of iron from the diet, rather than simply increasing the iron density of the diet (although this is also a reasonable strategy within limits). Improving iron absorption from the diet is an obvious strategy, but it is difficult to implement in a vegetarian, cereal-dominated diet which includes factors that inhibit iron absorption. Inhibition from the effect of polyphenols in tea is also relevant in this context.

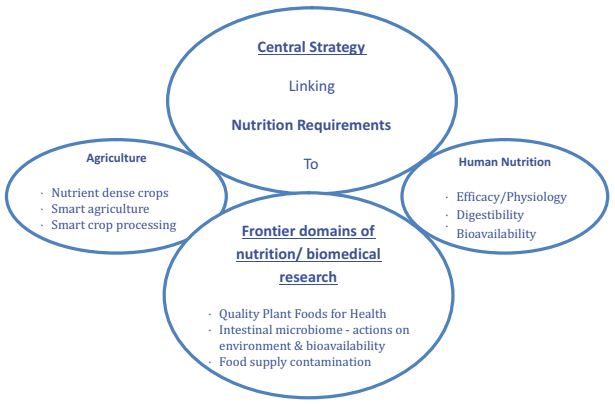
One of the important enhancers of iron absorption is vitamin C, but this is scarce in cooked foods. Also, raw fruits with a high vitamin C content are scarce in many diets, because of their high cost and seasonal availability. There is therefore an unarguable need for a diverse diet, rather than a single-nutrient approach in which the fortificant density is calculated based on the assumption of a very low bioavailability. A diverse diet can also be termed food-to-food fortification, in which real foods with good nutrient density are added to the diet, in fresh or processed form, such that a reasonable bioavailability is achieved.

Bringing concepts together – nutrient density

Nutrient density estimation is a method of evaluating the nutritional quality of a food or diet, by comparing the amount of nutrients supplied in relation to the energy content. The nutrient density of foods can be reported as the amount of specific nutrients per unit energy, or per 100 g of food intake. The estimation of nutrient density is important for evaluating the nutrient intakes of populations or individuals in order to assess whether age- and gender-specific minimum requirements are being met. Nutrient density is also used in nutrient profiling of foods, which is the technique used to rate, rank or classify foods based on their nutritional value[24]. In order to achieve the optimum nutrient density, it is critically important to achieve a balance between beneficial nutrients (proteins, dietary fiber, vitamins, minerals) and potentially adversarial nutrients that need to be limited (sugars, saturated fats, sodium)[25,26,27]. This is particularly true in the context of the complementary feeding of infants and children[28].

In order to meet the minimum energy requirements of individuals or populations, the consumption of a high-carbohydrate diet is likely to result in low nutrient density for essential micronutrients and proteins. Equally, a diet that is sugar-free and high in fat is also likely to have a low essential nutrient density. Both food-based and fortification strategies are options to consider in improving the nutrient density of a diet. For example, to increase the protein density in a vegetarian diet, foods such as pulses, whole grams and milk can be recommended. For increasing the iron density, enhancers such as vitamin C-rich foods (guava, amla, citrus foods) can be included.

Figure 5. The central location of the determination of nutrient requirements and risk for effective farm-to-plate transfer.



Another concept is that of the 'critical nutrient density'. This is the nutrient gap of a particular nutrient, which can be determined as the difference between the age- and gender-specific nutrient requirement on the one hand and the amount of nutrient provided by the actual food intake on the other. Critical nutrient density is calculated as the nutrient gap divided by the energy provided by the food consumed, and is expressed in per unit energy (100 kcal)[28]. For example, using the NNMB rural data[20] for children aged 1-3, 4-6 and 7-9 years, the calculated critical nutrient density for iron was low, at 0.46, 0.36 and 0.47 per 100 kcal, respectively. The optimal critical density of a nutrient should be $\geqslant 1$. If this analysis were performed for different micronutrients, one quickly gets an idea of the magnitude of multiple deficiencies. Importantly, this strategy also allows for evaluating food-to-food or chemical fortification strategies. Translating the concept of nutrient density to healthy daily diets will need a combination of nutrient profiling methods and other approaches to improve food habits and intake, with emphasis on sustainability and monetary costs.

Summary

India is facing a dual burden of nutrition related health problems; food quality, rather than quantity, is one of the key issues. The accurate definition of nutrient requirements is paramount to an understanding of food quality. This topic is now of global relevance, as it applies both to the nutritional needs of beneficiary populations across the developing world as well as to the nutritional quality of commodities currently available to meet the needs of human health throughout the human lifecycle. While concerns about the quantity of diet (in energy terms) were addressed in India through the Indian Food Security Act[29], the uncertainty about the coverage, as well as about the quality of diets that will actually be consumed, does potentially impact the nation's health, economy, agriculture and nutrient security. This is becoming especially relevant as India copes with the dual burden of under- and over-nutrition. There is a growing tendency for people to restrict their diets in order to offset the lower levels of physical activity. 'Eat less for your health' will have to be replaced with "eat less, but eat quality food".

Therefore, whereas India has many poor people on poor diets who can benefit from food fortification, it also has many people who eat excessive amounts of processed and fortified foods. Strategies to address these problems require that an informed regulatory process be put in place.

The epidemiological and operational science knowledge that exists in the public health space needs to be coupled with good physiological and mechanistic scientific approaches to determining nutrient requirements. This is a particularly exciting area of integrated research, since clinical, environmental and agricultural scientists can work together in frontier domains of natural sciences that inform food production and distribution, its efficacy and interaction with human physiology, as well as with the social sciences and policy (Figure 5). Examples are: arriving at an understanding of the interaction of the physiological status of the body with the environment and nutrient requirements; and the interaction between contamination (of the food supply, the environment, and the gut microbiome) and nutrient bioavailability and physiological outcomes.

The main considerations, therefore are: (i) to arrive at a definition of nutrient and food requirements in a framework that addresses both nutrient deficiency and nutrition excess, and (ii) a careful

examination of that framework in order to define the upper limits of nutrient intake specifically in the Indian context. This will happen if the excellent start given by the National Institute of Nutrition and the ICMR[1] by defining nutrient requirements is followed up.

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FOUNDATION NEWS

Annual Foundation Day: The Annual Foundation Day of NFI will be celebrated on 26th November, 2015. On this occasion Dr S Ramji (Director and Professor, Department of Paediatrics, Maulana Azad Medical College, New Delhi) will deliver the C Ramachandran Memorial Lecture on "Vitamin D and neonatal health".

One –day symposium
As part of the Foundation Day celebration, on 27th November, 2015, a one-day symposium will be held on the topic "MDG: lessons learnt and the way forwards to SDG".

NUTRITION NEWS

The 47th Annual Conference of the Nutrition Society of India will be held on 9th and 10th October, 2015, at National Institute of Nutrition, Hyderabad. The theme of the conference is 'Agriculture and Nutrition – the connect and the disconnect'.

At the Conference
• The Thirty Ninth Gopalan Oration will be delivered on 9th October 2015 by Dr. Prema Ramachandran (Director, NFI, New Delhi) on the topic "India's nutrition challenges".
• The Twenty Seventh Srikantia Memorial Lecture will be delivered by Dr. Vinod Paul (Prof and HOD Dept of Paediatrics AIIMS, New Delhi) on the topic "International foetal growth charts after MGRS".
• The Sixth Rajammal Devadas Memorial Lecture will be delivered by Dr Satyavati Rana on the topic "Nutrition and disease : an interaction"
Dr. K. Satyanarayana, former Director RMRC Bhubaneshwar, will receive the second B.K. Anand Award.

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