

Concept of a nutritious food: toward a nutrient density score¹⁻³

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ABSTRACT

The American diet is said to be increasingly energy-rich but nutrient-poor. To help improve the nutrient-to-energy ratio, the 2005 *Dietary Guidelines for Americans* recommend that consumers replace some foods in their diets with more nutrient-dense options. Such dietary guidance presupposes the existence of a nutrient density standard. However, a review of the literature shows that the concept of a nutritious food is not based on any consistent standards or criteria. In many cases, healthful foods are defined by the absence of problematic ingredients—fat, sugar, and sodium—rather than by the presence of any beneficial nutrients they might contain. Past attempts to quantify the nutrient density of foods have been based on a variety of calories-to-nutrient scores, nutrients-per-calorie indexes, and nutrient-to-nutrient ratios. The naturally nutrient rich (NNR) score, which is based on mean percentage daily values (DVs) for 14 nutrients in 2000 kcal food, can be used to assign nutrient density values to foods within and across food groups. Use of the NNR score allows consumers to identify and select nutrient-dense foods while permitting some flexibility where the discretionary calories are concerned. This approach has implications for food labeling, nutritional policy making, and consumer education. The Food and Drug Administration has considered approving nutrient claims based on the ratio of a beneficial nutrient to the food's energy content, as opposed to a specified minimum amount of a nutrient per serving size. Given the current dietary trends, the nutrient density approach can be a valuable tool for nutrition education and dietary guidance. *Am J Clin Nutr* 2005;82:721–32.

KEY WORDS Energy-dense food, nutrient-poor food, nutrient density standard, nutrition quality index, naturally nutrient rich score, food labels, health claims

INTRODUCTION

Rising rates of obesity and type 2 diabetes in the United States continue to be linked to a growing consumption of refined grains (1), added sugars (2), and added fats (3). Refined grains, fats, and sweets are inexpensive, palatable, and convenient (4–6). However, they can also be energy-dense (7) and are sometimes poor in vitamins, minerals, and other micronutrients (8, 9). The World Health Organization (7) has found sufficient evidence to link high consumption of energy-dense foods to the global obesity epidemic.

Concerns that the American diet has become energy-rich but nutrient-poor have been expressed for ≥ 3 decades (8, 10–12).

Energy-dense sweets and fats have long been contrasted, unfavorably, to foods that contained substantial amounts of key nutrients per serving or per unit weight. The terms *energy-dense* and *nutrient-poor* are commonly used to characterize foods perceived as unhealthy and to distinguish them from more nutritious options (8). Disparaging terms such as *junk foods* (13) or *empty calories* (14) are commonly used in antithesis to such descriptors as *healthful*, *packed with nutrients*, *nutrient-dense*, or *nutrient-rich*.

The problem is that nutrient-dense foods lack a common definition (15, 16). A 1977 review of the literature (15) showed that there were only limited efforts to define the concept of a nutritious food. General statements that such a food should provide “significant amounts of essential nutrients” were not backed by any firm standards or criteria (15). Three decades later, in 2004, there was still no agreement as to the definition of a nutrient-dense food or a healthful beverage (16). The various attempts to define and quantify the nutrient density of foods over the past 30 y are the topic of this report.

WHY A FOOD-BASED APPROACH?

As long as the consumer was advised that “all foods can fit” (17), there was no reason to emphasize the nutritional quality of individual foods. In keeping with the dogma that there are no good or bad foods, only bad diets (18), most measures of nutritional quality focused on total diets only, to the exclusion of single foods (19–22). Yet some of the early attempts to define the nutrient quality of individual foods, as opposed to diets, should not be overlooked (11, 15, 23–29). They may assist consumers in substituting the foods in their diets with healthier and more nutrient-dense options (30).

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TABLE 1

Common definitions of foods described as energy-rich or nutrient-poor

Term	What is meant	Reference
Empty calories	Not fruit, vegetables, dairy, meat, or bread	14
Junk foods	Oreo cookies ¹ , potato chips, laboratory chow	13
Energy-dense, nutrient-poor foods	“Other foods” (fats, sweets, and alcohol), other than meat, dairy, grain, fruit, or vegetable	37
	Visible fats, sugars, sweetened beverages, desserts, snacks	9
High-calorie, low-nutrient-dense foods	Candy, chips, soda, baked goods, ice cream	38
Low-nutrient-dense foods	Visible fats; cakes, cookies, donuts; soft drinks; sugar, syrups, jams; potato chips and corn chips; ice cream, sherbet, frozen yogurt	39
	Visible fats, sweeteners, baked and dairy desserts (eg, cookies, cakes, pies, pastries, ice cream, puddings, cheesecake), salted snacks, coffee and tea	40
	“Red foods” ¹ : >5 g fat/serving or low in nutrient density; fats, oils, sweets, combination foods (pizza, hamburger, lasagna)	41
Low nutrient-density foods	Fat, sugar, candy, soft drinks, baked desserts, dairy desserts, salted snacks, coffee, tea	42
	Baked and dairy desserts, sweeteners, salty snacks, visible fat, coffee, tea	43
	Cakes, cookies, pastries; carbonated beverages; sugars, jams, syrups; salty snacks	44
Energy-dense snack foods	Baked goods, ice cream, chips, sugar-sweetened soda, candy	45
“Bad” foods	Meat, fried potatoes, cheese, butter, margarine, white bread, pancakes, cookies, ice cream, candy, sugar	46
Unhealthful competitive foods	Fat >30%, saturated fat >10%, sugar >15 g, caffeine	47
Foods of minimum nutritional value	<5% of the US recommended dietary allowance for protein, calcium, iron, vitamin A, vitamin C, riboflavin, thiamine, niacin (per serving)	47

¹ Kraft Foods Nabisco Brands, Niles, IL.

Shifting attention from diets back to foods, the Food and Drug Administration (FDA) Commissioner observed in 2003 that “people shouldn’t need a calculator or an advanced degree in math or nutrition to calculate what makes a healthy diet” (31). Instead, the consumer was encouraged to rely on food labels and on the FDA Nutrition Facts Panel to identify and select healthier foods (32). Since then, the FDA Obesity Working Group has issued a report on weight management that focuses on counting calories and on making each calorie count more (33).

Looking for creative ways to revise the food label, the FDA considered listing the nutrient density of foods (31, 33). The nutrient density standard, as defined by the FDA, is the ratio of the amount of beneficial nutrients relative to the food’s energy content per reference amount customarily consumed. The more nutrient-dense foods are those that contribute more beneficial nutrients than calories to the overall diet. The FDA has proposed to allow health claims if a food meets a nutrient density standard, as an alternative to containing a minimum specified amount of a given nutrient per serving (32). Taking the food-based approach even further, the Federal Trade Commission (FTC) recommended to the FDA that it permit case-by-case health claims, even if the product does not meet a nutrient density standard, if such claims would help consumers substitute healthier foods in their current diets (30).

The 2005 *Dietary Guidelines for Americans* made a distinction between nutrient-dense foods and discretionary calories (34). By selecting the nutrient-dense foods first, consumers will meet the recommended nutrient intakes without exceeding their energy allowance. Discretionary calories could be consumed later, in proportion to energy needs (34). However, the ability to

make healthier substitutions—within or across food groups—depends on being able to identify and select the more nutrient-dense foods (30). To act on dietary advice, consumers will need easy ways to compare different foods on their nutrient density, nutrient-to-energy ratio, or some other objective measure of nutritional value. As long as nutrient density remains undefined (16), the concept of a nutritious food is all too often a matter of personal opinion.

These issues need to be resolved if future nutrition policies are to adopt the nutrient density approach. For example, an agreed-on nutrient density standard would help school boards decide on the type of snacks and beverages that should be placed in school vending machines (35). A nutrient-to-energy ratio could also be used to plan meals and diets for groups (36). Given the potential significance of the nutrient density approach to dietary guidance and public health, it is surprising how few recent studies have explored the concept of a nutritious food.

NUTRIENT-RICH COMPARED WITH NUTRIENT-POOR FOODS

Although there is little consensus as to the nature of nutrient-dense foods, a review of the literature shows a remarkable consistency when it comes to foods described as nutrient-poor. The various expressions that are used to disparage foods containing refined grains, added sugars, and visible or added fats are summarized in **Table 1**. Although the terms are not always factually correct (sweetened soft drinks are energy dilute), and the assignment to categories are not always consistent, foods described as nutrient-poor are largely those found at the bottom and at the top



of the US Department of Agriculture (USDA) Food Guide Pyramid (48).

There is less agreement as to the foods characterized as nutrient-rich. Nutrient-dense foods are often defined not in terms of the nutrients they contain, but in terms of being fat-free and sugar-free. Kant and Schatzkin (37) initially categorized foods consumed by adults in the second National Health and Nutrition Examination Survey (NHANES II) into 6 groups: meat, dairy, grains, fruit, vegetables, and "other." In their analysis, foods from the "other" group, ie, fats and sweets, displaced the more nutrient-dense foods from the diets of NHANES II participants (37). The "nonnutrient-dense foods" were accordingly defined by what they were not, ie, not meat, not dairy, not grains, and not vegetables or fruit. Later definitions acknowledged that the nonnutrient-dense foods were in fact visible fats, sugars, sweetened beverages, snacks, and desserts (9).

In other studies also, healthy foods were defined by the absence of undesirable nutrients, generally fat, sugar, and sodium. The University of Michigan Grocery Shopping Guide, an early attempt at point-of-sale guidance (49), assigned foods into "best," "acceptable," and "occasional" choices. These assignments were largely based on the food's content of fat, saturated fat, cholesterol, sugar, and sodium. Because the guide was developed for preventive cardiology, the "best" choices were usually those that were fat-free or low-fat; were low in saturated fat, and were good sources of fiber. The best foods also tended to be sugar-free and low in sodium (49). The fruit could have no added sugars, whereas the vegetables had to contain <480 mg Na. In contrast, the beneficial nutrients that the "best" foods ought to contain were never fully specified. The absence of problematic nutrients was the main point.

Similarly, the National Heart Lung and Blood Institute defined healthy foods by low amounts of fat (<12 g), saturated fat (<4 g), cholesterol (<100 mg), and sodium (<480 mg) per serving (50). The definition of healthy foods adopted by the American Heart Association was also based on the virtual absence of fat (≤ 3 g), saturated fat (≤ 1 g), and cholesterol (≤ 20 mg) and on a low sodium content (≤ 480 mg) per serving (51). Likewise, the 2003 Food Guide Pyramid made few distinctions among foods within food groups that were not based on their fat and sugar contents (52). The major concern was that consumers not get too many calories or too much fat, saturated fat, cholesterol, sugar, sodium, or alcohol (52).

In dealing with problematic nutrients, the FDA has taken the position that health claims can be used only if a serving of food contains <13 g fat, <4 g saturated fat, <60 mg cholesterol, and <960 mg Na. Whereas all of the "absence" criteria had to be met, the criteria for the presence of beneficial nutrients were more permissive. Per FDA rules, healthy foods should contain $\geq 10\%$ DVs per serving for at least one of the following: protein, calcium, iron, vitamins A and C, and fiber (53). Using comparable criteria, the USDA had defined foods of minimum nutritional value as those that failed to provide 5% of the reference daily intakes per serving for 8 key nutrients: protein, calcium, iron, vitamin A, vitamin C, riboflavin, thiamine, and niacin (47).

Attempts to translate dietary guidelines into practice, as formulated by professional associations and expert panels, have also tended to focus on the negative. Typically, the emphasis was on avoiding too much fat, saturated fat, cholesterol, sugar, and sodium (54). The American Diabetes Association (55) explained

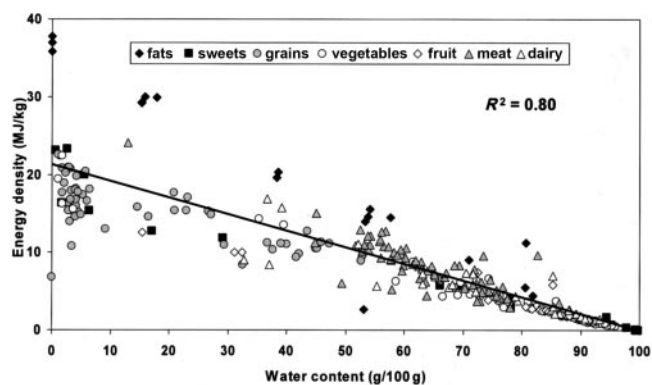


FIGURE 1. Relation between energy density and the water content of foods.

that "sugary foods don't have the nutrients, vitamins, and minerals that your body needs to be healthy. That's why we call these calories empty and list these foods in the top of the Food Guide Pyramid." The World Health Organization (8) has cautioned against the excessive consumption of energy-dense foods, notably those high in sugar and fat. The 2000 Dietary Guidelines Committee expressed concern over sweetened but energy-dilute beverages, which provided "significant calories and no nutrients" (56).

The advice to limit the consumption of energy-rich foods is grounded in the assumption that energy density and nutrient density are inversely linked. In reality, as shown in Figure 1 and documented before (57), the energy density of foods is not always determined by their sugar and fat contents. Often, energy-dense foods are simply those foods that are dry. Water, which provides weight but no calories, influences the energy density of foods more than does any macronutrient, including fat (57). Examples of dry energy-dense foods are candy and potato chips, but also whole grains and cereals. In contrast, soft drinks, fruit, vegetables, and milk are energy-dilute (57). Although the overall inverse relation between energy density and nutrient density may hold, not all energy-dense foods are necessarily nutrient-poor or vice versa. The automatic assignment of all energy-dense foods into the "bad" category seems arbitrary and is not based on any particular metric or scale.

WHAT ARE NUTRIENT-DENSE FOODS?

The term nutrient density means different things to different people. To epidemiologists, the term *nutrient density of the diet* means crude nutrient intakes (in g or mg) divided by the total energy intakes (58). In epidemiologic studies, nutrient density often means diet composition, as indexed by the percentage of energy from carbohydrate, protein, and fat (58). In developmental nutrition, a nutrient-dense food is one that delivers a complete nutritional package and can be used to sustain life (59). For example, Briend (60) described a nutrient-dense infant feed as one composed of milk protein, peanut butter, oil, and sugar and fortified with vitamins and minerals. By contrast, in the cancer prevention literature, vegetables and fruit are classified as being nutrient-dense (61), whereas the presence of oil and sugar would be enough to classify a food as being nutrient-poor (9).

TABLE 2Common examples of foods described as healthy, healthful, nutrient-dense, or nutrient-rich¹

Term	What is meant	Reference
Nutrient-dense foods	Milk, vegetables, protein foods, fruit, grains	66
Nutrient-dense food groups	Dairy, fruit, grain, meat, vegetable groups (LND foods excluded)	40
High-nutrient-density foods	Fruit, vegetables, milk, whole-grain products	67
Nutrient-dense beverages	100% juice, milk	68
Nutrient-dense foods	Fruit, cheese, yogurt, cereals	69
“Good” foods	Fruit, vegetables, cucumbers, spinach, tomatoes, beans, low-fat milk, whole-grain bread, oats, salmon, fish	46
Healthy foods	Fresh fruit, cooked vegetables, raw vegetables and salad, olive oil	70
Healthy foods	Fish, fruit, vegetables, nuts, whole-grain cereals	7
Healthful foods	Fruit and vegetables, meats, grains, dairy products	71
Healthy foods (diabetes)	Diet soda, 1% or skim milk, high-fiber bread, low-carbohydrate bread, fresh fruit, fresh tomatoes, fresh green vegetables	72
Healthful snacks	Vegetables, fruit, pretzels, yogurt	73
Healthful vended snacks	Pretzels, peanut butter and cheese crackers, peanuts, almonds	74

¹ LND, low nutrient density.

The literature mentions nutrient-dense carbohydrates (62), nutrient-dense meats (63), nutrient-dense milk (64), nutrient-dense fruit and vegetables (61), and nutrient-dense nuts (65). The present review is based on studies that listed the terms nutrient density, nutrient-dense, or nutrient-rich either in the abstract or in the title. As shown in **Table 2**, the definition of nutrient-dense foods seems to encompass all grains, meats and dairy products, vegetables, and fruit.

In the absence of agreed-on standards, there are continuing differences of opinion as to which foods are truly nutrient-rich. For example, in 1979, Hansen wrote that “with the exception of thiamin, the nutrients provided by breads and cereals are not particularly notable” (8). In his view, the main importance of cereals was that they provided calories, protein, thiamine, calcium, and iron at a very low cost (5, 8). In contrast, other researchers have described breads and cereals as being nutrient-rich, and the current literature refers to nutrient-dense carbohydrates (75, 76) and nutrient-packed whole grains (62). There are also differences of opinion regarding fruit juices: some researchers describe 100% juices as nutritious (68, 69), whereas others do not (77). In an extreme case, even the nutritional value of milk was challenged, as described in a recent review (78).

There have been several attempts to formally define what is meant by nutritious foods. In 1974, the FTC proposed to limit the use of the term nutritious to foods that provide $\geq 10\%$ of the US RDA for protein and 3 other nutrients per 100 kcal and $\geq 10\%$ of the RDA per serving for one of these nutrients. However, as Guthrie (15) had pointed out, only one vegetable and one milk out of a total of 135 different foods met those very stringent criteria. Burroughs (79) then suggested that the foods designated as nutritious ought to provide 50% of the US RDA for one nutrient, 20% for 2 nutrients, 15% for 3 nutrients, 10% for 4 nutrients, and 6% for 5 nutrients. The last criterion was apparently based on the assumption that each person consumes 15 different foods per day, so if each of those foods were to provide 6% of nutrient requirements, the person would be well-nourished (15). However, Burroughs’ criteria were almost as strict. Such foods as tomatoes, whole-wheat bread, Cheddar cheese, and peanut butter failed to qualify under that standard (15). Similarly, in a more recent study of vending sites at a large university (74), only 4 of

133 unrefrigerated snacks met a nutrients-for-calorie criterion for nutrient density (8) that was based on 7 nutrients and fiber.

Aiming to quantify nutritional value, Hansen et al (8) suggested that such terms as poor, fair, adequate, good, or excellent might be used to reflect the gradations of nutrient density. That was an early precursor of the FDA criteria for the allowable use of such terms as “a good source of” and “excellent source of.” Those terms are based on percentage DVs, but they apply to only one nutrient at a time and not to the total nutrient package. Health claims are permitted if the food, before fortification, contains $>10\%$ per serving of DV for protein, calcium, iron, vitamin A, or vitamin C. The FDA definition precludes health claims for fruit and vegetable products with added oils, salt, sauces, or syrups as well as some breakfast cereals. In keeping with the FDA position, the National Cancer Institute excluded from its definition of healthy foods processed fruit and vegetables that contain sugar or fat or that contain >480 mg Na. However, that position may be changing. In 1995, the FDA invited comment on whether processed vegetables and fruit ought to be exempted from the minimum nutrient requirement (30). The FTC response was that frozen vegetables in sauce or canned fruit in light syrup can contribute to healthier diets (30) and that a nutrient density standard would allow health claims for many of those relatively nutrient-rich foods.

Some concepts of nutritional value depend on membership in a given food group. For example, the National Cancer Institute included in its former definition of healthy foods *all* fruits and vegetables in their natural form, with the exception of avocados, nuts, olives, and coconut (80). The exclusion of avocados, now rescinded, was based purely on fat content and did not take the beneficial nutrients in avocados into account. Recognizing that not all foods within a food group have the same nutritional value, the World Health Organization defined nutrient-dense foods as whole grains, lean meats, low-fat dairy products, and all legumes, vegetables, and fruit (7). Going beyond the sugar and fat contents of foods, the Food Guide Pyramid emphasizes that dark green leafy vegetables and legumes are especially good sources of vitamins and minerals and recommended fresh fruit, fruit juices, and frozen, canned, or dried fruit. There was no prohibition



against nuts, which were included alongside meat, poultry, and fish (52, 81).

In contrast with the systematic approach adopted by the health agencies, many other attempts to grade the nutrient density of individual foods appear arbitrary, tautologic, and imprecise. In the Traffic Light Diet (41), individual foods are categorized as green, yellow, or red on the basis of their (unspecified) nutrient density. Red foods are described as being higher in energy density than the foods in the other groups. Green foods (most vegetables and fruit) are described as “very high” in nutrients and low in fat. In another study (82), foods of moderate nutrient density were simply described as being less nutrient-dense than were the foods that were high in nutrient density. In the examples given, fat-trimmed beef was contrasted with skinless poultry, low-fat with nonfat milk, and candied sweet potatoes (one of the highest sources of carotenoids found in nature) with plain vegetables. For reasons that were not clear, the former were all deemed to be less nutrient-dense than the latter.

Working with a list of 60 Swedish foods, Michels and Wolk (46) stated that they “simply” categorized foods as good or bad on the basis of their (unspecified) nutrient content and on data from large epidemiologic studies. All meat was bad and therefore not recommended; white bread (high glycemic index), cheese (too much saturated fat), and margarine (*trans* fatty acids) were also not recommended. Poultry did not make the list of recommended foods because the researchers did not consider chicken to be a health-promoting food (46); juices (too much sugar) and boiled potatoes (high glycemic index) also did not make the list. Whole milk and 3%-fat yogurt were judged to be about as desirable as alcohol and did not count toward either food score. Escaping censure were crispy rye bread, lettuce, cucumber, tomatoes, salmon, herring, and other fish (except shellfish)—in other words, the classic ingredients of an open-face Swedish sandwich. When it comes to deciding which foods have nutritional value, some researchers seem to share the viewpoint of the Supreme Court Justice Potter Stewart: “I know it when I see it” (83).

NUTRITIONAL ADEQUACY OF DIETS

The traditional ways of evaluating the nutritional adequacy of diets were based on comparisons of nutrient intakes with the RDAs (*see* 19 for review). The 2 key measures were the nutrient adequacy ratio (NAR) and the mean adequacy ratio (MAR). The NAR is the ratio of intake of a given nutrient relative to the RDA for that nutrient. The MAR is then calculated by averaging the sum of the NARs for a number of nutrients. The intent of the MAR score was to evaluate the intake of selected nutrients relative to the recommended values (19). For example, the nutrient adequacy ratio in WIC (Women, Infants, and Children) diets was measured by dividing the children’s intakes of energy and 8 nutrients by the RDAs for a child that age (84).

The consumption of nonnutrient-dense foods is reported to be on the rise (85), and the typical American diet now derives close to 40% of energy from added sugars and fats (5). If the diet does undergo further nutrient dilution, then the calories-to-nutrients ratio will increase. Meeting the RDAs, therefore, will be associated with higher energy intakes because people will need to consume more energy to obtain the recommended (or adequate) nutrients. The Food and Agriculture Organization (FAO) of the United Nations has suggested replacing the RDA-driven measures of diet quality with the nutrient density approach (86). In

TABLE 3
Comparison of nutrient density standards¹

Nutrient	FAO	ERFP	DRIs
Protein	40–50 g	64 g	46–56 g
Vitamin A	700–1000 μg RE	1000 μg	700–900 μg
Vitamin C	50–60 mg	200 mg	75–90 mg
Calcium	500–800 mg	1,536 mg	1000–1200 mg (AI)
Iron	7–40 mg	32 mg	8–18 mg
Zinc	12–20 mg	21 mg	8–11 mg
Folate	300–400 μg	620 μg	400 μg
Thiamine	1.0–1.6 mg	2.4 mg	1.1–1.2 mg
Riboflavin	1.2–1.8 mg	2.4 mg	1.1–1.3 mg
Vitamin B-12	1.0–2.0 μg	24 μg	2.4 μg
Vitamin D	5.0–10.0 μg	10.4 μg	5–15 μg (AI)
Vitamin E	7.0–10.0 mg	32 mg	15 mg
Niacin	12–20 mg	22.4 mg	14–16 mg
Vitamin K	40–80 μg	120 μg	90–120 mg (AI)
Vitamin B-6	1.2–2.0 mg	2.4 mg	1.3–1.9 mg
Fiber	16–40 g	—	21–38 g (AI)
Potassium	—	3.4 g	4.7 g (AI)

¹ Nutrients of public health importance as listed by the Food and Agriculture Organization (FAO) of the United Nations (86); Nutrient values (2000 kcal) for Emergency Ration Food Product (ERFP) as listed by the Institute of Medicine (90); recommended dietary allowances for adults (>18 y) based on dietary reference intakes (DRIs) from the Institute of Medicine; Adequate intakes (AI) where indicated (91, 92).

their view also, the nutrient-to-calorie ratios provide a more direct comparison between the intake of essential nutrients and the amount of energy that the food provides. The nutrient density concept is most useful when energy intake is low and it is essential that nutrient-rich foods be included in the diet. The concept was applied by the FAO to the development of food-based dietary guidelines (86). The favored foods were those that made a greater contribution to nutrient intakes than to meeting total energy needs.

The use of the RDAs in determining diet quality was based, in part, on the assumption that a wide variety of food choices will ensure that all the nutrient requirements are met. However, dietary variety can be a function of socioeconomic status (87). Even in 1979, families in the middle- and upper-income brackets consumed more meat, poultry, fish, milk and milk products, and fruit and vegetables, whereas poor people ate more breads and cereals (8). The revisions in the WIC food package in the late 1970s and 1980s helped low-income groups to obtain foods rich in key nutrients: protein, calcium, iron, and vitamins A and C (88). The ongoing challenge is to provide foods that maximize the nutrient-to-calorie ratio and do so at an affordable cost (5, 87).

TOWARD A NUTRIENT DENSITY STANDARD

Nutrient density is defined as the ratio of the nutrient composition of a food to the nutrient requirements of the human (8). To compare the 2, calories are the most appropriate common denominator, as opposed to food servings or portion sizes. Formal comparisons between the nutrient composition of foods and reference DVs are meaningful only if made on a standard per calorie basis—usually per 1000 or 2000 kcal (8, 89). The resulting nutrient density ratio is then independent of serving size (8).

To construct nutrient density ratios, we need to have the nutrient composition of different foods and a set of reference standards (8). Three sets of standards, each one developed for different purposes, are summarized in **Table 3**. The FAO allowances for nutrients with relevant public health implications provide for a range of nutrient values for a 2000-kcal/d diet, depending on age, sex, and special needs. No physiologic relation between energy and nutrient requirements is implied. This is merely a convenient way of expressing the nutritional adequacy of a given diet, assuming sufficient consumption of energy (8).

The second set of standards, specifying a minimum required nutrient density per 2000 kcal, was developed by the Committee on Military Nutrition Research of the Institute of Medicine (IOM) for an altogether different purpose. It was intended for a nutritionally complete emergency relief food product capable of satisfying all nutrient requirements of a population (age > 6mo) that could be the sole source of subsistence for up to 15 d (90).

Dietary Reference Intakes (DRIs), based on the report of the Food and Nutrition Board of the IOM (91, 92), are shown in **Table 3**. The DRIs are quantitative estimates of nutrient intakes that can be used for planning and assessing diets of healthy persons. Percentage DVs are often calculated on the basis of the upper limit of the DRIs.

HANSEN'S NUTRITIONAL QUALITY INDEX OF FOODS

An index of food quality, initially proposed in 1973 (11, 24), was later renamed as the index of nutritional quality (23) and then as the Nutritional Quality Index (NQI) of foods (8). The NQI measured the amount of nutrient in a food relative to the food's energy content, using the US RDAs for each nutrient as the reference standard, based on the consumption of 2000 kcal energy. At the time, the daily intake values were 900 mg for calcium, 16 mg for iron, 60 mg for vitamin C and 350 mg for cholesterol (8). Computed separately for each nutrient, the NQI was the ratio of its percentage standard relative to the percentage standard of calories. In other words, if a given food contained X mg of a nutrient in C kcal and the US RDA for that nutrient was Y mg in 2000 kcal, then

$$\text{NQI} = (X/Y)/(C/2000) \quad (1)$$

The NQI can also be expressed as the ratio between the amount of a nutrient in a portion that meets energy needs (ie, 2000 kcal) and the recommended allowance for that nutrient, also based on 2000 kcal. The 2 expressions are mathematically equivalent (15).

NQI values >1.0 may be desirable or not, depending on the nutrient in question. For example, NQI values >1.0 may be viewed as desirable for calcium or iron but as undesirable for saturated fat, cholesterol, or sodium. Although Hansen's NQI index provided a number of useful nutrient-to-calorie comparisons, it stopped short of measuring the overall nutritional quality of a food product (28). Instead, the NQI was more of a nutrient-by-nutrient profile based on the food's content of 18 nutrients, including carbohydrates, fat, saturated fat, and cholesterol (**Table 4**). Its authors recommended the nutrient density approach as a unified, scientifically justifiable way to improve the diet quality of individuals and groups (93).

In one early application (94), the nutrient composition of fast foods consumed away from home was found to be sufficient in

TABLE 4

Comparison of key nutrients used to construct nutrient density scores¹

NQI	RRR score	CFN	NNR
Energy	Energy	—	—
Protein	Protein	Protein	Protein
Vitamin A	Vitamin A	Vitamin A	Vitamin A
Vitamin C	Vitamin C	Vitamin C	Vitamin C
Calcium	Calcium	Calcium	Calcium
Iron	Iron	Iron	Iron
—	—	Zinc	Zinc
—	—	Folate	Folate
Thiamine	—	Thiamine	Thiamine
Riboflavin	—	Riboflavin	Riboflavin
Vitamin B-12	—	Vitamin B-12	Vitamin B-12
—	—	—	Vitamin D
—	—	—	Vitamin E
Niacin	—	Niacin	—
Vitamin B-6	—	Vitamin B-6	—
MUFA	—	—	MUFA
Fiber	Fiber	—	—
—	—	Magnesium	Potassium
Carbohydrate	Sugar	—	—
Sodium	Sodium	—	—
Saturated fat	Saturated fat	—	—
Cholesterol	Cholesterol	—	—
Total fat	—	—	—

¹ NQI, Nutritional Quality Index (8); RRR, ratio of recommended to restricted (96); CFN, calories-for-nutrient (29); NNR, naturally nutrient rich; MUFA, monounsaturated fat.

protein and adequate in various other nutrients. With the exception of soft drinks, the NQI values for protein, thiamine, riboflavin, and niacin in fast foods were >1.0; however values for vitamins A and C, folate, and magnesium were <1.0 in most instances (94). More recently (95), the NQI was used to assess the nutrient quality of foods offered through food pantries to low-income families. Pantry foods were found to be of high nutritional quality (NQI >1.0) for protein, fiber, iron, and folate. The NQI scores were 1.0 for total fats, 0.9 for saturated fats, and 0.3 for cholesterol. However, the foods offered were of low nutrient density for calcium (NQI = 0.4) and vitamin C (NQI = 0.1) (95). In other words, the food pantries lacked vegetables and fruit, milk, yogurt, and cheese.

RATIO OF RECOMMENDED TO RESTRICTED FOOD COMPONENTS

In 1977, Guthrie (15) suggested that the nutrients found on the food label might serve as a basis for constructing a single measure to reflect the food's overall nutrient quality. The ratio of recommended to restricted (RRR) food score (96), published in 2004, was based on energy and the nutrients listed on the food label. The RRR food score computed the ratio of the "good" to the "bad" nutrients and to the energy content of the food. Six nutrients (protein, calcium, iron, vitamin A, vitamin C, and fiber) were defined a priori as desirable, whereas 5 nutrients (energy, saturated fat, cholesterol, sugar, and sodium) were defined as undesirable (Table 4). The percentage DVs for all nutrients were calculated, and the mean percentage DV for the good nutrients



was then divided by the mean percentage DV for the bad nutrients, such that

$$RRR = (\sum \%DV_{\text{recommended}}/6)/(\sum \%DV_{\text{restricted}}/5) \quad (2)$$

A similar NQI, developed by Moorman (97) and also based on nutrients listed on the food label, was used to measure changes in the nutritional quality of brand-name packaged foods between 1993 and 1996. The desirable nutrients were calcium, iron, vitamin A, vitamin C, and total vitamin B. The undesirable nutrients were total fat, saturated fat, unsaturated fat, cholesterol, and sodium. Calories were excluded. Any time that the quantity of a desirable nutrient increased in a food product, the product was awarded a +1 score. If the amount of an undesirable nutrient increased, the product received a -1 score. Because Moorman's index was designed to measure change, as opposed to the baseline nutritional quality of a given food product, its applications remain limited.

PADBERG'S NUTRITION QUALITY INDEX

The Padberg index (29), also based on nutrients listed on the food label, was another attempt to assess the overall nutrient quality of foods. Foods received points depending on whether the food met a nutrient content claim for that particular nutrient, as defined by the FDA. On the basis of these threshold criteria, a product containing >20% DV for a given nutrient was characterized as "an excellent source" and if it contained 10–20% it was characterized as a "good source." Foods containing <10% DV of a given nutrient are not permitted source claims (31). Although the nutrients were not explicitly labeled as good or bad, every nutrient on the label, except for sugars and calories from fat, received a point score. Products containing >20% DV were assigned 100 points, those containing 17–19% got 75 points, those containing 14–16% got 50 points, those containing 10–13% got 25 points, and those containing <10% got 0 points (29). Although the index ranged from 0 to 100 points, in reality each nutrient was rated along a 5-point category scale. Because calories were a part of the index, foods with <274 kcal per serving would get 100 points, whereas any food with >482 kcal per serving would get 0 points. Not surprisingly, Padberg's NQI favored lower-calorie foods, independent of their nutrient content.

The total points were then divided by the number of nutrients to arrive at a mean score. The step functions were smoothed by averaging them, to remove any incentive for manufacturers to reformulate food products near the step points (29). In contrast with prior indexes, the Padberg NQI was a weighted score. The importance of each nutrient was estimated on the basis of data from a survey of 372 dietitians who were asked to rank groups of 3 nutrition labels in terms of perceived nutrition value (98). The effect that each nutrient had on ranking choices was derived from logit regressions. Quality points were then weighted by the importance that the dietitians had assigned to each nutrient. However, a subjective nutrient popularity poll has inherent limitations, because the prevailing opinions can change. In 1993, at the height of the fat phobia, dietitians assigned substantial importance to total fat (weight 0.30) and saturated fat (weight 0.17) but viewed calcium as less important (weight 0.04) and virtually disregarded iron (weight 0.00005).

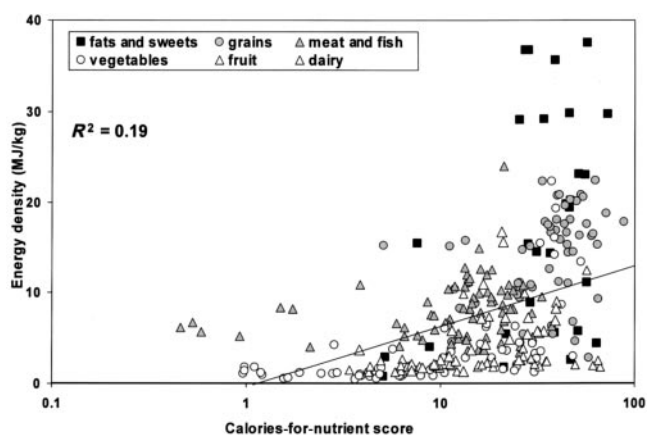


FIGURE 2. Relation between energy density and the calories-for-nutrient score.

THE CALORIES-FOR-NUTRIENT SCORE

The calories-for-nutrient (CFN) score, developed by Lachance and Fisher (28), was a more direct assessment of the relation between food energy and nutrient value. In effect, the CFN score calculated the caloric penalty for each increment in the nutrients consumed from a given food. The CFN score was defined as the cost in calories that was required to obtain an additional 1% DV for a range of key nutrients. Initially developed with the use of 9 nutrients, the CFN score was later expanded to 13 (28).

The 13 nutrients used by Lachance and Fisher were protein, calcium, iron, vitamin A, vitamin C, thiamine, riboflavin, vitamin B-6, vitamin B-12, niacin, folic acid, magnesium, and zinc (Table 4). To compute the CFN score, the percentage DVs for each nutrient were calculated based on 100 g food. The average percentage DV was calculated by summing all 13 DVs and dividing that value by 13. The energy density of the food (ED; in kcal/g) was then divided by the mean percentage DV.

$$CFN = ED/(\sum \%DV_{100\text{g}}/13) \quad (3)$$

The lower the CFN value, the lower the cost in calories to obtain the nutrients associated with a given food. The CFN score was an unweighted mean of percentage DVs and all 13 nutrients contributed equally to the total score. Consequently, a low-scoring food might appear to be nutritionally balanced, although the score could be driven low by large amounts of a single nutrient. Although sugar and fat were not part of the CFN score, the energy density calculation did introduce the energy value of foods into the equation. Dividing energy density by mean percentage DV had the effect of favoring energy-dilute foods.

The relation between the energy density of foods and a modified CFN score (based on 14 nutrients) is shown in **Figure 2**. The CFN scores were calculated for the ≈ 220 food components in the food-frequency questionnaire developed by the Fred Hutchinson Cancer Research Center. The list included foods from all the food groups, including beverages, fats, and sweets. However, zero-calorie beverages (tea, coffee, and diet soft drinks) were excluded, as were fortified foods. Beverages, juices, and cereals fortified with vitamins and minerals were excluded, as were formula diets and dietary supplements.

Not surprisingly, fats and sweets were both energy-dense and relatively nutrient-poor. For other food categories, added sugars

TABLE 5

Fourteen key nutrients and recommended daily values (DVs) based on the dietary reference intakes that were used to calculate the naturally nutrient rich scores¹

Nutrient	Value
Protein	65 g
Vitamin A	5000 IU
Vitamin C	75 mg
Calcium	1300 mg
Iron	18 mg
Zinc	11 mg
Folate	400 μ g
Thiamine	1.2 mg
Riboflavin	1.3 mg
Vitamin B-12	2.4 μ g
Vitamin D	10 μ g
Vitamin E	15 mg
MUFA	20 g
Potassium	3500 mg

¹ From references 91 and 92. MUFA, monounsaturated fat.

and added fat increased the energy cost of beneficial nutrients. For example, ice cream, milkshakes, and frozen yogurt provided nutrients as well as energy. In contrast, skim and low-fat milk, yogurt, and cottage cheese provided the same nutrients at a much lower energy cost. Similarly, the caloric penalty for nutrients in lean meats was substantially lower than for nutrients in fatty meats or fried chicken.

THE NATURALLY NUTRIENT RICH SCORE

The 14 nutrients forming the naturally nutrient rich (NNR) score were selected based on past efforts to define healthy diets (8, 28, 36, 86). For example, 5 key nutrients (protein, calcium, iron, vitamin A, and vitamin C) are integral to the WIC program because they are most likely to be lacking in the diets of low-income women (84). The WIC program also tracks the intakes of folate, vitamin B-6, and zinc. Among the additional nutrients of public health significance, as listed by the National Cancer Institute (39), are fiber, carotene, magnesium, and vitamin E; an even broader list is provided by the FAO (86).

The NNR score is a nutrients-to-calories ratio. The initial version of the NNR Index was based on 14 nutrients: protein, calcium, iron, vitamin A, vitamin C, thiamine, riboflavin, vitamin B-12, folate, vitamin D, vitamin E, monounsaturated fat, potassium, and zinc (Table 4). These nutrients are very similar to those previously used by Lachance and Fisher (28). A more recent version of the NNR score added fiber and vitamin B-5 (pantothenic acid), for a total of 16 nutrients (99).

Percentage DVs were calculated based on 2000 kcal food. The reference amounts were the upper limits of the recommended intakes for individuals as provided by the Food and Nutrition Board (Table 5). Consistent with the FDA approach, the foods were assessed for the nutrients they contained in relation to the food energy they provided.

In its simplest version, the NNR score was the average of %DVs for 14 key nutrients:

$$\text{NNR} = \frac{\sum \%DV_{2000 \text{ kcal}}}{14} \quad (4)$$

The energy density of foods did affect the NNR score. Because the percentage DVs were calculated based on 2000 kcal food, the

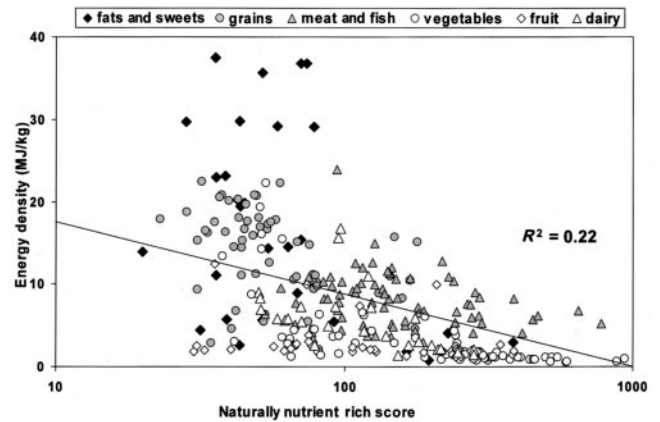


FIGURE 3. Relation between energy density and the naturally nutrient rich score (truncated).

values for some energy-dilute foods could be extremely high. For example, 2000 kcal red peppers delivers a DV of several thousand percent for vitamin C. One solution to the problem (suggested by Guthrie in 1977) is to truncate percentage DVs at some arbitrary limit (2000% DV) before the NNR index score is calculated. In this way, the contribution of any one nutrient does not contribute unduly to the total NNR index score.

The relation between the energy density of foods (kcal/g or MJ/kg) and the 14-nutrient NNR score is plotted along a logarithmic scale in Figure 3. The low end of the range was truncated at 10; only some sweetened beverages scored lower than that. The bad or undesirable nutrients did not enter into the NNR score. The score was not reduced if the food contained fat, saturated fat, sugar, cholesterol, or sodium. However, because the percentage DVs were calculated based on 2000 kcal, energy density did enter into the calculations and the less energy-dense foods did tend to have higher scores.

A comparison of Figures 2 and 3 showed that the 2 indexes, calories-for-nutrient and nutrients-for-calorie, are mirror images of each other. Given that all fortified foods were excluded, both indexes showed an inverse relation between the energy density of foods (MJ/kg) and their nutrient density. When it comes to unfortified foods, the more energy-dense foods were, in general, more likely to be nutrient poor.

NUTRIENT DENSITY WITHIN FOOD GROUPS

The intent of the 2005 *Dietary Guidelines for Americans* was to assist consumers in selecting the more nutrient-dense options within each food group. The NNR score provides a useful way to assign a nutrient density score to each food. Figure 4 shows the relation between energy density and the NNR scores for vegetables and fruit. With some exceptions, such as nuts, fried potatoes, and potato chips, most vegetables and fruit were low energy-density foods. Their NNR scores were accordingly high. The more caloric items, such as raisins or fruit in heavy syrup, had lower NNR scores than did fresh grapes, fruit in light syrup, or other fresh fruit. Green leafy vegetables such as spinach had a very high nutrient-to-calories ratio; however, the NNR score does not at this point take nutrient bioavailability into account. Importantly, fat content did not preclude avocados or nuts from having relatively high NNR scores, when calculated based on a nutrient-to-energy ratio. Similarly, legumes such as peas, beans,



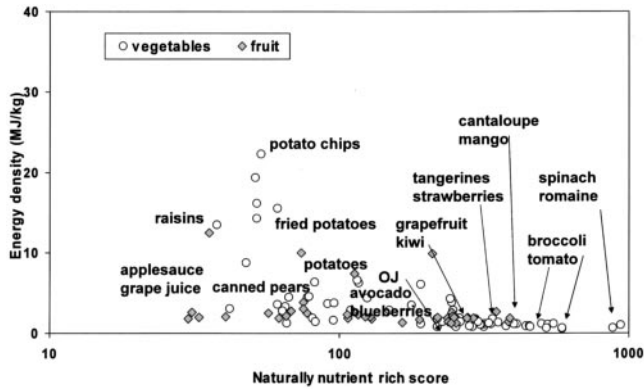


FIGURE 4. Relation between energy density and the naturally nutrient rich score for vegetables and fruit. OJ, orange juice.

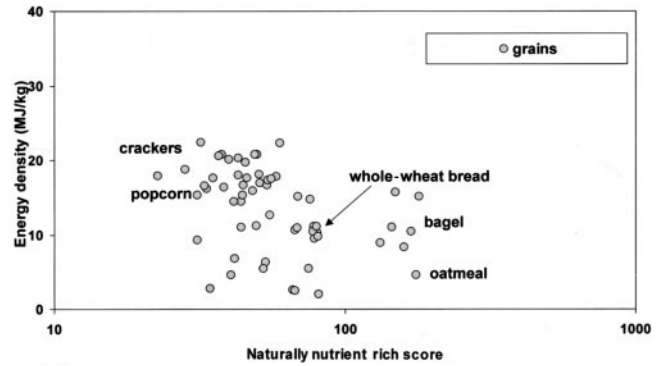


FIGURE 6. Relation between energy density and the naturally nutrient rich score for grains.

or lentils received high NNR scores despite their relatively high energy density.

The relation between the energy density of meats and dairy products and their NNR scores is shown in Figure 5. Because of their high water content, lean meats and low-fat dairy products are relatively low energy-density foods. The NNR scores accurately ranked milk products according to their fat content. Skim and low-fat milk scored higher than whole milk, whereas plain yogurt had a higher NNR score than did frozen yogurt or ice cream. In the meat category, lean cuts of beef and lean ground beef scored higher than regular ground beef, which in turn scored higher than fried chicken.

The relation between the energy density of grains, fats, and sweets and their NNR scores is shown in Figure 6. Whole-grain products scored higher than some bakery goods, sweets, and desserts. However, there was a great deal of variability within the grains group because not all grains are energy-dense and not all energy-dense products are nutrient-poor.

DISTRIBUTION AND BIOAVAILABILITY OF NUTRIENTS

A nutrient density standard that can be objectively applied to individual foods can help in prioritizing dietary choices along the lines suggested by the 2005 Dietary Guidelines Committee (34) and the FDA. However, many important factors still need to be

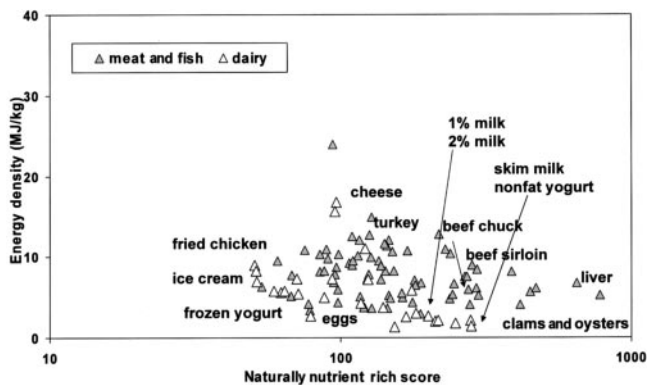


FIGURE 5. Relation between energy density and the naturally nutrient rich score for meat and dairy products.

considered. Chief among these are the biological quality of nutrients in the food source, their bioavailability, and the distribution of the nutrients in the food supply. At this time, the NNR score is not weighted, and each nutrient is assigned the same importance. However, there are past precedents for developing a weighted nutrient density score, with some nutrients assigned higher weights (29). Those weights can be based on nutrient bioavailability and on whether or not the nutrient is widely distributed.

Whereas some nutrients are widely distributed, others are restricted to a narrower range of food sources or are found in sufficient quantities in a small number of foods. Using foods from the USDA Handbook No. 8, Hansen et al (8) listed the percentage of foods with NQI values of ≥ 1.0 for the different food groups. Not surprisingly, the meat (92%) and milk (84%) groups had the highest proportion of foods with high NQI values for protein. The milk group also had the highest proportion of food with high scores for calcium (86%); vegetables had the second highest scores(60%). The only foods offering substantial amounts of vitamin C were vegetables (93%) and fruit (80%).

A preliminary ranking of the nutrient content of >200 component foods from a food-frequency questionnaire showed that some nutrients were more broadly distributed than others. For comparison purposes, each nutrient was expressed as percentage DV in 2000 kcal food. Most of the foods contained protein. On the other hand, only a fraction of foods contained vitamin C, most of them vegetables and fruit. Relatively few foods contained vitamin E and vitamin B-12, which makes these 2 nutrients nonubiquitous. A weighting system for the NNR score could be based on the distribution and the relative rarity of the nutrients in the food supply.

The bioavailability of nutrients by food source (100) would be another way to weight the NNR score. Calcium in milk is more bioavailable than is the calcium in spinach, whereas heme iron in meat is more bioavailable than is the iron in plant-based products. A weighted NNR score would also take bioavailability into account.

These questions await further research and the validation of the NNR approach. One question is whether the NNR will predict diet quality, as established with the use of existing measures. At this time, no link has been established between the NNR score and other measures of diet quality, such as the Healthy Eating Index. On the other hand, there are data suggesting that the nutrient density of frequently consumed foods does have an effect on the consumption of key nutrients in the diet. Kant and

Graubard (43) showed that the more frequent consumption of “low-nutrient-dense” foods by children and adolescents was associated with lower dietary intakes of calcium, iron, vitamin A, vitamin B-6, folate, magnesium, and zinc.

Such work raises the question of whether future versions of the NNR ought to include a score based on the problematic or undesirable nutrients. The present NNR score, which focuses on beneficial nutrients only, represents a departure from the view that the healthiest foods are those that do not contain fat, saturated fat, cholesterol, sugar, or sodium. However, some approaches to assessing the nutrient density of foods did use the ratio of good-to-bad nutrients, and future versions of the NNR may include a negative component as well.

One limitation of the present NNR approach is that it is based wholly on the consideration of food chemistry. Physiologic consequences of food consumption, such as glycemia or satiety, are not taken into account. Future assessments of the nutritional value of foods may need to be based on a combination of food biochemistry and human physiology.


APPLICATIONS OF THE NNR SCORE

There are mounting concerns that low-cost energy-dense foods are eroding the nutrient density of the American diet. Fewer than 15% of Americans meet the Healthy Eating Index criteria for a healthy diet (85) or consume adequate servings of foods recommended by the Food Guide Pyramid (48). The reported 300-kcal/d increase in energy intakes in the period 1985–2000 was largely accounted for by grains and added sugars and fats, rather than by milk and dairy, vegetables, or fruit (6, 101, 102). Public health nutritionists are concerned that we have become an overfed yet undernourished nation (103).

There is a growing interest in helping consumers maximize the nutrient-to-calorie ratio. The nutrient density standard, as formulated by the FDA and operationalized by the NNR score, computes nutrients in foods relative to the energy that the foods provide. The FDA has expressed an interest in redesigning the food label using a nutrient density standard and the nutrient-to-energy ratio (30, 32). Certainly, the nutrient density standard can be used as a platform for consumer education; there are also immediate needs when it comes to school nutrition and the development of meals and diets for groups (104). This approach opens the door to future research that joins studies on the nutrient density of individual foods with studies on the overall quality of the total diet (105). The question is whether a diet composed of high-scoring NNR foods would be optimal in terms of calorie content and nutrient distribution, as recommended in the current guidelines.

A nutrient density approach to improving the diets of the elderly is already in place (106–108). As energy intakes decline with age, it is important to consume more of the nutrient-dense foods so that the recommended nutrient intakes do not decline below an acceptable level (108). Calculations of the nutrient density of diets per 1000 kcal as a function of age have been published (109). The same nutrient density approach could also be applied to weight control.

Whereas counting calories has been the main strategy for weight control (33), application of the nutrient density standard will make each calorie count more. Focusing attention on the nutrient-to-calorie ratio, the NNR score allows consumers to identify the more nutrient-dense foods within each food group

and make their food selections accordingly. Adherence to a naturally nutrient-rich diet requires the consumption of more colorful fruit and vegetables, whole grains, lean meats, seafood, eggs, beans and nuts, and low-fat and nonfat dairy products. The NNR score is a potentially useful adjunct to the 2005 *Dietary Guidelines for Americans* and offers a promising approach to consumer education and dietary guidance. 

AD reviewed the literature and wrote the manuscript.

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