Defining and interpreting intakes of sugars[1–4]

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ABSTRACT This paper clarifies the myriad of terminologies used to describe intakes of sugars by American consumers. In addition, it carefully critiques information sources used to explain and interpret consumption levels. Sugars are incorporated into foods for their biological, sensory, physical, and chemical properties. By chemical definition, the sugars normally consumed are the monosaccharides and disaccharides: glucose, fructose, galactose, sucrose, lactose, maltose, and trehalose. US governmental agencies use 4 terms to describe sugars: *added sugars*, *caloric sweeteners*, *sugar*, and *sugars*. Different sources are included when measuring sugars. Knowledge regarding intakes of sugars relies on food intake surveys (primarily dietary recalls) and economic food availability estimates. Although intake data may underestimate actual consumption, availability data tend to overestimate it. Furthermore, the sugars contents of many foods appearing in composition databases are derived from the summation of recipe ingredients rather than from actual measurements. Intakes of sugars over time (trends) must be viewed within the context of varying definitions, changes in food composition, changes in dietary intake methods, and acknowledged increases in the underreporting of intake. Agreement is needed to identify one common definition to describe intakes of sugars. Convergence between intake data and economic availability data would more accurately depict consumption. Precise amounts of sugars within currently available foods should be measured, not calculated. Without a common language, accurate and precise measurements, and consensus among scientists, educators, regulatory agencies, and the public, conversations regarding any health effects of sugars may lead to continued misunderstandings. *Am J Clin Nutr* 2003;78(suppl):815S–26S.

KEY WORDS Sugars, consumption, food availability, food intake, Continuing Survey of Food Intakes by Individuals, CSFII, diet surveys, dietary assessment, economic food supply

INTRODUCTION

Humans are born with an innate preference for sweetness (1). In utero the fetus is surrounded by sweet amniotic fluid. At birth, most American infants are fed breast milk or commercial formula containing the milk sugar lactose. Thus, it is not surprising that a sweet preference would continue into adulthood. Throughout human history, sugars have been added to enhance the sweetness of foods. Different sugars added during food preparation, production, and preservation provide various degrees of perceived sweetness.

In addition to sweetness, sugars impart a wide variety of other favorable qualities to food (**Table 1**). Specific to baked goods and other processed foods, sugars impart several properties essential to product quality and safety (4), which are characterized as biological [substrate for the fermentation required for baking (leavening and texture) or antimicrobial preservation through the selective binding of water used in food recipes], sensory (taste, aroma, texture, appearance, and sweetness), physical [viscosity, ability to retain water, osmotic pressure, crumb tenderness, grain size, distribution (for texture control), consistency, and dryness], and chemical (caramelization, Maillard browning, and product antioxidation).

Sugar alcohols (sorbitol, mannitol, xylitol, maltitol, erythritol, and lactitol) are also added to foods for their functional roles. They add texture to gums and hard candies, increase food volume and moisture retention, and provide a cooling mouth sensation. Sugar alcohols are naturally occurring (mostly in fruit) or are produced by adding hydrogen to specific sugars (3, 4); they are poorly absorbed and partly fermented, accounting for their laxative effects (6).

The primary types of sugars used in the food supply are the various fructose- and nonfructose-rich corn syrups, cane and beet sugar (sucrose), and honey and other edible syrups. Cane or beet sugar is used, in descending order of frequency, in the following food products: bakery and cereal products; candy and other confectionary items; ice cream and dairy products; beverages; canned, bottled, and frozen foods; and an assortment of other miscellaneous foods (7). Corn syrups are used in beverages, processed foods, cereal and bakery products, dairy products, and candy and other confectionary items (7).

Given the widespread use of sugars in the food supply, one would assume that interpretations and discussions surrounding sugars and intakes of sugars would be relatively simple. Unfortunately, this simplicity does not exist because of the myriad of terms used to describe these ingredients, the lack of comparable dietary consumption data, the paucity of actual analyses of sugars in foods for composition databases, and the use of epidemiologic studies as the primary basis for current questions regarding the effect of sugars on health, specifically obesity and other chronic diseases. These shortcomings create communication difficulties and ultimately misunderstandings. These misunderstandings make it difficult to determine which, if any, health effects are solely the result of sugars consumption. Therefore, it is imperative to clearly understand the nuances and distinctions involved.

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TABLE 1
Summary of common sugars and their functions in food

Saccharide and function	Specifics	Application
Fructose		
Sweetness	Perception dependent on temperature, pH, solids content, and presence of other sweeteners (2) Faster, shorter, and more intense sweet taste than either sucrose or dextrose (2)	Fructose's flavor can be enhanced when used in conjunction with other sweeteners (eg, sucrose) (2) Other flavors in food products brought out when the sweetness of fructose rapidly leaves taste buds (2) Lower amounts of high-fructose corn syrup (40–90% fructose) can be used, satisfying sweetness yet resulting in a less caloric food product (3)
Ability to retain water	Absorbs water at a lower relative humidity, ≈55%, than does sucrose (>65%) (2)	Prevents food products from drying out, even in dry environments (2)
Humectant	Retains water in low-relative-humidity conditions (2)	Tender and moist texture for longer periods of time, more shelf-stable (2)
Viscosity	Lowers the gelatinization temperature of starch and magnifies the thickness of the product (2)	Products, such as puddings, acquire more thickness faster than if sucrose was used (2)
Microbial inhibitor	Competes with microbes for life-sustaining water; lowers water activity	Absorbs water, preventing microbial growth and therefore extending shelf life
Lowers freezing point	Because of its low molecular weight	Prevents ice crystals from rupturing cell walls in fruit; important consideration for frozen desserts (2)
Glucose, fructose, galactose, sucrose, lactose, and maltose		
Fermentation (4)	Yeast ferments sugars into alcohol and carbon dioxide	Carbon dioxide stretches gluten to facilitate its development, raises dough for bread making, and contributes to texture (5)
Trehalose		
Protection against freeze-thaw or freeze drying and rehydration	Nonreducing; highly resistant to hydrolysis, inert in interactions with proteins	May protect against the removal of water during dehydration or freezing (5)
Reducing sugars		
Color	Maillard browning	Gives bread crusts dark brown color; responsible for the "baked" color of microwaved products (2)
Invert sugar		
Texture	Inhibits crystallization	Prevents a grainy texture in hard candy (5)

For the purposes of examining health effects related to intakes of sugars, it is important to consider the following overarching issues before examining the available data: *1*) Are the reported data on intake of sugars valid? What are the strengths and limitations associated with each data source? How might these limitations affect subsequent interpretations of the data? When should the varying data sources be compared? *2*) What do trends in intake of sugars mean? How are trends affected by differences in populations surveyed across time, survey response rates, techniques used in data collection, other concurrent food and population trends, etc? *3*) What epidemiologic evidence suggests that various intakes of sugars (dose response) might be associated with health? Which doses are problematic across the range of intakes? Does the cause precede the effect? Are there other confounding factors? *4*) What is the clinical evidence to support direct health risks at the various sugars intakes? Do the associations seem biologically plausible and clinically relevant? *5*) What are the assumptions and expectations underlying the suggestion that lower intakes of sugars will achieve predicted health effects? *6*) What clinical data support quantifying (setting) an intake for sugars? *7*) What is the correct terminology to describe the intake of monosaccharides and disaccharides plus a small amount of oligosaccharides: sugar, sugars, added sugars, gram equivalents, caloric sweeteners, or free sugars? Will a consistent definition succeed in clarifying the issues? *8*) How should information be presented to health professionals, consumers, regulatory agencies, policy makers, and other interested parties?

To logically address these issues, this article first will describe commonly used definitions and terms and then briefly review the absorption, digestion, and metabolism of sugars. A description and critique of intake data in general and sugars in particular will be addressed next, followed by a review of current intakes. Then, dietary guidance issues and consumer perceptions will be described. Last, implications for future research will be presented.

SUGARS BASICS

Nutrition science (chemical) definitions

Chemically, the term *sugars* refers to a group of compounds comprising carbon, hydrogen, and oxygen atoms and classified as either monosaccharides or disaccharides (**Table 2**). Monosaccharides contain 3–7 carbon atoms per monomer and are the absorbable form of sugars (11). Glucose, fructose, and galactose are the primary monosaccharides in the human diet; mannose plays a minor role (**Figure 1**) (12). These monosaccharides assume either an α or β configuration, with thermodynamic stability determining which anomeric configuration predominates. The 5-, 6-, and 7-carbon monosaccharides exist in solution as ringed structures (Figure 1).

Disaccharides are 2 monosaccharides (2 monomers) joined together. Primary disaccharides in the human diet are sucrose (one molecule of α-glucose and one of β-fructose), lactose (β-galactose and α- or β-glucose), trehalose (2 molecules of α-glucose, 1→1

TABLE 2
Definitions

Term used	Source	Definition	Measurement
Consensus definitions used within workshop			
Sugars	Consensus	Refers to monosaccharides and disaccharides (1 and 2 monomers only); sometimes seen in the literature as simple sugars	
Sugar	Consensus	Refers strictly to sucrose	
Oligosaccharides	Consensus	Refers to compounds containing 3–9 monomers	
Commonly used definitions to describe sugars in food			
Added sugars	Food Guide Pyramid (US Departments of Agriculture and Health and Human Services; 8)	Eaten separately or used as ingredients in processed or prepared foods (such as white sugar, brown sugar, raw sugar, corn syrup, corn syrup solids, high-fructose corn syrup, malt syrup, maple syrup, pancake syrup, fructose sweetener, liquid fructose, honey, molasses, anhydrous dextrose, and crystal dextrose). May contain oligosaccharides	Teaspoon
Sugars	Food Label—*in the Nutrition Facts Panel* (Food and Drug Administration; 9)	All monosaccharides and disaccharides (includes naturally occurring sugars as well as those added to a food or drink, such as sucrose, fructose, maltose, lactose, honey, syrup, corn syrup, high-fructose corn syrup, molasses, and fruit juice concentrate). Any oligosaccharides present in these compounds are not counted.	Grams
Sugar	Food Label—*in the Ingredients Statement* (Food and Drug Administration; 9)	Indicates sucrose in ingredients statement	None
Caloric sweeteners	Food Disappearance Data (Economic Research Service, US Department of Agriculture; 10)	Sweeteners consumed directly and as food ingredients (such as sucrose (from refined cane and beet sugars), honey, dextrose, edible syrups, and corn sweeteners (primarily high-fructose corn syrup); contains oligosaccharides	Grams Teaspoons

linkage), and maltose (2 molecules of α-glucose, 1→4 linkage) (**Figure 2**). The same α or β terminology is applied to the internal glycosidic linkage that joins the 2 monosaccharides when the disaccharide is formed (12). Humans contain enzymes that cleave these linkages into the component monosaccharides in preparation for subsequent absorption and metabolism.

Syrups contain a third group, the oligosaccharides (composed of compounds containing 3–9 monomers). The oligosaccharide content (by wt) of commercially available fructose-rich corn syrups may be as high as 2.4%. This estimate is based on the 60–80 split between HFCS-42 and HFCS-55 reported in the food supply in 2000. This represents ≈9.3% of the reported weight of the nonfructose corn syrups (13) or as much as two-thirds of the saccharide content of some of these products (9).

Definitions used throughout this workshop

For consistency, the workshop attendees reached consensus regarding the use of the terms *sugar*, *sugars*, and *oligosaccharides*. The definitions of these terms are found in Table 2.

Commonly used definitions and terminologies

Whereas there is concordance about the chemical definitions, these terms are not used to communicate information about sugars. Rather,

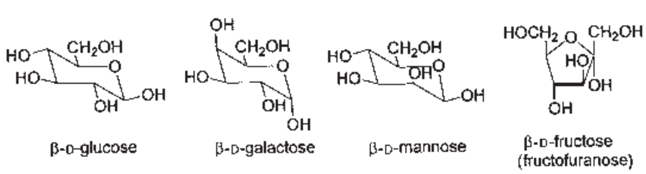

FIGURE 1. Primary monosaccharides in foods.

in the United States, 4 distinctly different terms—*added sugars, sugars*, *sugar*, and *caloric sweeteners*—are used by 2 government agencies. The US Department of Agriculture (USDA) issues dietary guidance, and the Food and Drug Administration (FDA) regulates foods and food ingredients. Each term is described in detail in Table 2.

Added sugars (USDA) and caloric sweeteners [Economic Research Service (ERS), USDA] omit naturally occurring sugars, such as those in fruit and dairy products. Although the FDA includes only monosaccharides and disaccharides in its sugars category on the Nutrition Facts label, the ERS includes oligosaccharides present in the various high-fructose and nonfructose corn syrups in its caloric sweeteners category. Confusion exists about whether boiled (stripped, deodorized, and decolored) fruit juices are included within the added sugars categories, but the FDA does include them as a component of total sugars for the Nutrition Facts Panel. In addition, in 2002, the FDA issued a regulation that prohibits the claim of "no added sugar" for products containing any amount of sugars added during processing or packing or any other ingredient that contains sugars that functionally substitute for added sugars (eg, jam, jelly, and concentrated fruit juice) (14).

Another additional complication arises when the USDA reports percentages of individuals reporting 1-d consumption of foods from various food groups by sex and age. In this case, the value given for sugars refers to white sugar, brown sugar, saccharin, aspartame, and other sugar substitutes and excludes sugars that were ingredients in food mixtures coded as a single item and tabulated under another category (Table 10.6 of reference 15). For example, sugars added to baked goods and candy are not included in this table.

In common vernacular, *sugar* refers only to table sugar (sucrose). The ultimate result of these multiple definitions is the potential for inconsistency and misinterpretation by consumers, scientists, and regulators alike. This is of major concern when addressing the issues of sugars and health because the body cannot

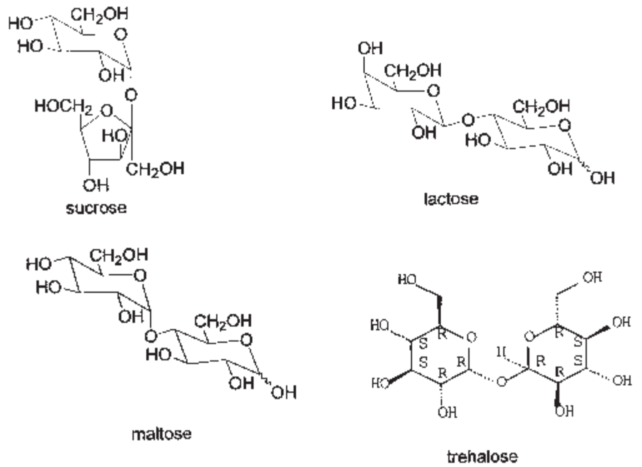

FIGURE 2. Primary disaccharides in foods.

distinguish naturally occurring monosaccharides and disaccharides from those added to food during processing, during cooking, or at the table or from those formed during the digestion of complex dietary carbohydrates (16).

Absorption and digestion of monosaccharides and disaccharides

Although some digestion occurs in the mouth and stomach, disaccharides and oligosaccharides from any food source remain relatively undigested, for the most part, until entering the small intestine (12). Unlike the absorption of other nutrients, the absorption of sugars occurs independent of dietary sources. At the surface of the small intestine, the brush border enzymes maltase, sucrase, trehalase, and lactase break down maltose, sucrose, trehalose, and lactose, respectively, into their constituent monosaccharides (17). The absorption of glucose and galactose is dependent on ATP produced by the sodium-potassium ion pump. Hence, they are absorbed through the small intestine primarily by active transport. Fructose is absorbed by either facilitated diffusion or active transport, with both transport mechanisms being saturable (12). The absorption of fructose is slower than that of glucose and galactose but faster than that of sugar alcohols (12). Trehalase is bound to the intestinal membrane and transported into the cell, where it is broken down into glucose (18).

On absorption, monosaccharides pass through the enterocytes of the small intestine into the portal circulation and are transported to the liver, where glucose, galactose, and fructose are phosphorylated. The liver takes up galactose and fructose more efficiently than does glucose, which remains in the bloodstream for delivery to the brain, kidneys, muscle cells, and adipocytes to be used for energy (12). Glucose is the preferred energy source for brain cells (the prime exception is during long-term fasting, during which ketone bodies can be utilized) and for red blood cells. In the liver, galactose and fructose are converted to glucose (19). This primary physiologic need for glucose by the brain cells is the basis for the recently established estimated average requirement of carbohydrate for children and adults, 130 g/d (19). Depending on energy needs, glucose is either stored as glycogen (highly branched chains of glucose units) or released into the bloodstream to be metabolized by body tissues (12).

Metabolism of sugars

Glucose, fructose, and galactose can be metabolized for energy. Each has an energy value of 15.7 kJ/g (3.75 kcal/g) and produces

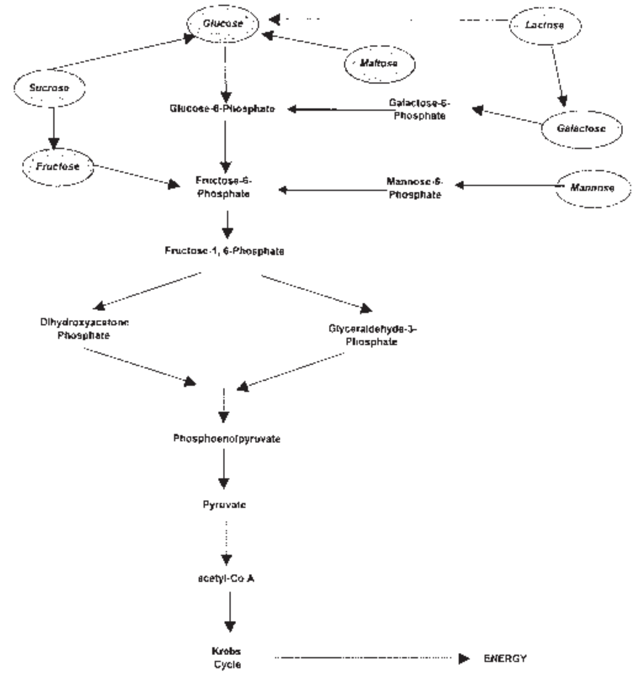

FIGURE 3. Glycolytic pathway.

≈38 mol ATP/mol monosaccharide (6). The primary metabolic pathway is glycolysis. Although glucose, fructose, and galactose enter the glycolytic pathway at different points, each ultimately produces 2 pyruvate molecules (**Figure 3**). Pyruvate is either oxidized completely through the Krebs cycle and the electron transport chain to produce ATP, carbon dioxide, and water under aerobic conditions or is converted into lactate under anaerobic conditions.

Glucose is stored in the liver and muscle as glycogen. Glycogen storage, however, is limited by the amount of accompanying water. Glucose not used for immediate energy needs or stored as glycogen can be converted through de novo lipogenesis into fat for storage in adipocytes. However, this conversion is energetically costly. Astrup and Raben (20) calculated that 68% more energy (155 compared with 42 MJ/kg) is required to increase body fat stores by 1 kg when carbohydrate (15–30% sucrose solution) is overfed than when fat is overfed. In their review of a study that compared isocaloric carbohydrate or fat overfeeding (21), Astrup and Raben (20) state, "It is difficult to increase fat mass in normal-weight subjects, particularly on carbohydrate overfeeding."

CRITIQUE OF DATA SOURCES FOR AND USES OF SUGARS INTAKE DATA

Food-consumption data are usually obtained by 2 distinct methods: soliciting information directly from individual persons (intake data) and estimating the usage by the population from economic food availability data (food supply data) (**Table 3**). Neither method is perfect or complete, although both methods provide important epidemiologic insights. Any discussion of the intake of sugars must take into account the nutrient databases from which intakes of sugars are determined. An overview of the effect of these information sources on the values, presented as intakes of sugars, is provided in

TABLE 3
Data sources of sugars and sweeteners used to determine intakes of sugars

Data	Source	Method
Sugars intake and information		
Continuing Food Intake by Individuals (15)	US Department of Agriculture	Telephone 24-h dietary recall, 1 or 2 d
National Health and Nutrition Examination Survey (22)	Centers for Disease Control and Prevention and National Center for Health Statistics	In-person 24-h dietary recall, 1 d only
Diet and Health Knowledge Survey (15)	US Department of Agriculture	Telephone survey
Trends survey (23)	Food Marketing Institute	Consumer survey
Food availability		
Per capita food availability data (24)	Economic Research Service and Agricultural Research Service, US Department of Agriculture	Estimation of caloric sweeteners remaining after deducting commodity supplies (the sum of production, beginning inventories, export, and industrial consumption) and retail, food service, and home losses. Per capita availability is calculated by dividing this value by the US total population, including the armed forces overseas, on July 1.

Table 4. The following sections examine these information sources as they relate to determination of the health effects of sugars.

Individual food intake data

The 2 major surveys used to estimate food intakes were the Continuing Survey of Food Intakes by Individuals (CSFII) and the National Health and Nutrition Examination Survey (Table 3) (26). Data obtained from individual interviews are weighted to accommodate the complexity of the sampling procedures and the large sample sizes. For descriptive purposes, data are often subdivided into age-sex groups to define individual means for that group. Individual dietary information can be obtained by using food records, 24-h dietary recalls, food-frequency questionnaires, and food histories (27). For the intake of sugars, the 24-h method is used most often. The strengths of this method include the ability to probe deeply into amounts eaten and preparation methods, defined time period, ability to quantify, short administration time, high response rates, ease of administration (in person or by telephone), and ability to adjust for sampling and intake distributions (weighting of the data).

These surveys rely on self-reported (retrospective) dietary recalls (28). Although they provide insights into potential health issues, these studies have recognized limitations. They are cross-sectional in design; thus, they provide snapshots only of the particular years respondents were interviewed. Because respondents are different from one set of survey years to another, identification of and support for trends can be inferred but not confirmed. Inherent to cross-sectional studies is the fact that data cannot be used to establish causality (29). Furthermore, cross-sectional data cannot determine displacement of one food by another, because displacement assumes that one beverage was used instead of another (30). For example, Kant (22), using cross-sectional data, noted that it was unknown whether children would have consumed higher intakes of milk or juice in the absence of carbonated soft drinks. Cross-sectional data provide no information regarding previous or subsequent intakes beyond the days of dietary intake nor what an individual person might do if presented with other food choices.

Most commentaries on the limitations of self-reported food intake focus on accuracy (31, 32). Recall precision is subject to short-term memory and to portion-size estimations (28). Respondent biases can range from underreporting selective foods and body weight to overreporting body heights (33). In recent years some have hypothesized that individual persons selectively underreport their intakes of foods generally known to be high in fats, carbohydrates, and sugars (34–36). Inaccurate perceptions of portion size as well as issues of guilt, embarrassment, inconvenience, and social desirability influence the underreporting of food intake (31). Omissions of foods less central to the meal were noted when weighed foods were compared with subsequent 24-h dietary recalls (37). In one study, foods consistently underreported were side dishes (eg, potatoes, salad, vegetables, and breads) and condiments (eg, salad dressings and gravy), and foods consistently accurately reported were main entrées, beverages, and desserts (37).

TABLE 4
Effect of the components of data sources on values representing the intake of monosaccharides and disaccharides

Data source and issues	Effect
Food intake (15)	
Accuracy	Underestimates due to underreporting
Pyramid groupings	Overestimates because the added sugars in the pyramid tip include oligosaccharides
Food availability (24)	
Accounting for food service, retail, and home losses	Direction uncertain because not actually measured
Inclusion of oligosaccharides	Overestimates because these are not monosaccharides or disaccharides
Includes sugars used by nonfood and beverage industries	Overestimates amount available for food and food ingredients
Food composition (25)	
Use of recipe calculations rather than direct analyses	Overestimates because sugars are used by yeast and in Maillard reaction (browning of baked goods, cereals, and other products) during food production
	Underestimates if starch breakdown results in monosaccharide and disaccharide production

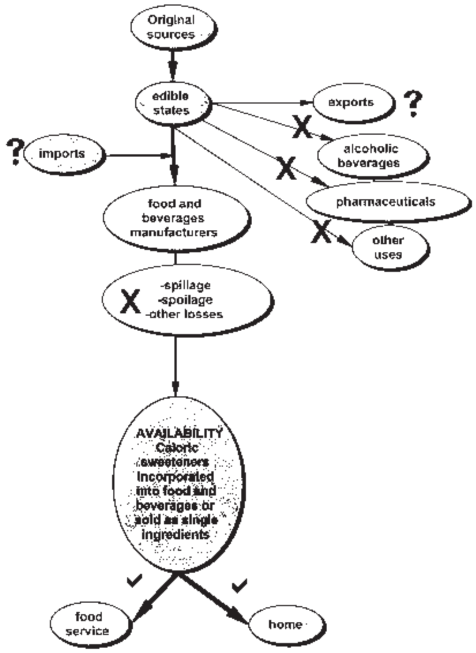

FIGURE 4. Food availability schema for caloric sweeteners. ✕, amounts not accounted for in availability data; ✓, estimated amounts of losses accounted for in availability data; **?**, not included in availability values.

When comparisons are made between intakes and body mass index (BMI), few correlations or significant differences are generally noted between energy or nutrient intakes and BMI. In other words, those with the highest BMI do not report the highest levels of consumption of specific nutrients or of energy. Whether the lack of correlation is due to underreporting of weight, underreporting of food intake, overreporting of height, or some combination, bias in reporting has been detected. Of respondents to the 1994 CSFII, those with greater body fatness or lower literacy levels appeared to underreport food intake (38). Lack of correlation should not be surprising because BMI is the result of food intake and energy expenditure over time, whereas food intake data (regardless of its accuracy) are obtained at a unique time and do not address energy expenditure. The paucity of information regarding the energy expenditure (ie, physical activity levels) of respondents further complicates the issues.

Self-reported data are vulnerable to the quality, consistency, and training of the interviewers as well as to the recall accuracy of the respondent. In the 1994–1996 CSFII, both 1-d and 2-d dietary recalls were collected, whereas only 1-d dietary recalls were collected in the National Health and Nutrition Examination Survey. When only 1-d recalls are used to report intakes, the findings provide no information on within-individual variations and tend to overestimate between-individual variations.

Underreporting, interview techniques, and interviewer training were addressed in the 1994–1996 CSFII by using an intensive 3-pass interviewing technique (39). The initial pass focused respondents (≥ 11 y of age) on what they ate and drank over the previous 24 h. Questions about the timing of intake and naming of eating occasion were then asked. Respondents were prompted to recall additional foods not mentioned. The third and final pass gathered detailed descriptions, amounts, and food sources. For children < 6 y of age, the primary caregiver was interviewed. For children between 6 and 11 y of age, the child was interviewed and additional information was supplied by the adults in the household who prepared the children's food, by childcare providers, and from school lunch menus. This method has reportedly reduced the percentage of respondents classified as low-energy reporters (those who report implausibly low energy intakes) from 25% in the 1989–1991 CSFII to 15% in the 1994–1996 survey (34). Because this improvement results in more accurate dietary recalls, trends can be misconstrued, a critical concern when trying to determine whether the noted increase in consumption of sugars and sugar-containing foods is real or the result of improved measurement. Despite its limitations, food intake data provide valuable insights into food choices, and hence nutrient intakes, on which intakes and chronic diseases relations hypotheses can be created.

Food availability data

USDA's ERS is responsible for providing the economic analyses that track annual US food and food ingredient production. Over the years these analyses provide data to measure the effects of a changing food supply, determine the ability of the food supply to meet the population's nutritional needs, determine national nutrition policies, and suggest nutrient-disease relations (26). Several factors limit the application of these estimated values to considerations of the effect of consumption on health and overall nutritional status, including how availability figures are derived (eg, which foods and ingredients are included or excluded).

Basically, the total food or food ingredient remaining—after exports from the sum of annual production and initial inventory are subtracted—is the amount reported as available for all commercial uses. This amount is termed *economic consumption* and is generally reported on a per capita basis. Thus, per capita economic consumption is a calculated measure of the total supply of a food or food ingredient commercially available.

The ERS uses the term *caloric sweeteners* when describing the total available commercial supply of sucrose and other sugars sources. The products the ERS considers to be caloric sweeteners are listed in Table 2. This category includes multiple components destined for a variety of commercial uses, of which incorporation into foods and beverages is the primary application (eg, an estimated 1% is used by the alcoholic beverage industry; J Putman, ERS, personal communication, 2002), although current availability data have not been adjusted for by this loss. Caloric sweeteners are also used in the pharmaceutical and pet food industries. Currently, the extent of these uses is not easily located.

A schema for estimating the availability of caloric sweeteners is presented in **Figure 4**. Although sugars in imported and exported processed foods are not included in the availability data, it is likely that the net difference is small and does not appreciably affect per capita consumption trends (J Putman, personal communication, 2002). The ERS estimates losses that occur at the retail (1%) and food service and consumer levels (30%) (Table 7 of reference 40). Food service losses occur when too much food is made and when customers' leftovers are discarded. At home, food losses occur from discard during preparation, during cooking, or from plate waste; overpreparation; and product spoilage, spillage, and cooking failures (10). The ERS does not account for potential losses occurring at the manufacturing sites during food production, although such losses are accounted for by the ERS for other food products. Given that there are losses of unknown magnitude, caution must be taken when attempting to explain consumption on the basis of availability data.

The global approach used by the ERS (determination of per capita food availability estimates) does not allow for the examination of the use of caloric sweeteners by age and sex. The ERS assumes equal usage across the population (by dividing the adjusted availability estimates of caloric sweeteners by the total population). Because food intake survey data have already detected differences in sugars usage by age and sex subgroups, it becomes difficult to determine demographic trends with the use of availability data. Furthermore, the data cannot be used for statistical analyses because such use would violate the basic premise of normal distribution required by most statistical tests.

Following trends in relation to food availability data may be more helpful than following trends in relation to food intake data because the definition of caloric sweeteners has not changed over time. However, trends in caloric sweeteners would be more meaningful if estimates were also available for the nonfood and nonbeverage usages of these ingredients. This would allow comparison of the percentage of caloric sweeteners for these uses to the percentage used by the food and beverage industry over the same period and would increase our ability to reflect on the implications of caloric sweeteners in relation to health.

Food-composition information

Food intake surveys primarily use values from the National Nutrient Data Bank (USDA Food Composition Laboratory) in either the USDA Nutrient Database for Standard Reference or the food-composition database used for national food surveys (41). Additionally, in 1985, a separate publication (Home Economics Research Report no. 48) issued by the Human Nutrition Information Service listed the individual and total sugars contents of 500 selected foods (25). Some food manufacturers supply additional nutrient information. Sugars values appearing in any of these databases can be obtained either through direct chemical analyses or by mathematical calculations. Direct food analyses are conducted by using either HPLC or gas chromatography (42). The distinctive elution order permits accurate measurement of fructose, glucose, sucrose, and maltose. The actual amounts of sugars in fruit and vegetables vary according to maturity, year, storage conditions, and cultivar.

Virtually every public and commercial nutrient and food consumption study relies on these sources. For some foods, information on added sugars is not available. However, when the total and individual sugars contents of prepared food products are stated on the label, most values are calculated from recipes of the unprepared forms rather than from direct analysis. For example, none of the sugars values for breads or candies listed in the Home Economics Research Report no. 48 were actually measured (25). Calculations are generally the sum of the individual sugars-containing ingredients in the recipes. Thus, these values are an estimate of the sugars content and may misrepresent the actual amounts in the prepared product. Overestimation may result if some recipe sugars are unavailable because of the Maillard reaction and caramelization or because some sugars are no longer present because of fermentation (leavening). In a comparison with a chemically leavened dough system, 3 different yeasted dough mixtures were analyzed by HPLC (43). No changes occurred in the sugars composition of the chemically leavened products, but 54–91% of the sucrose in the yeasted dough was hydrolyzed during mixing and sponge fermentation. Underestimation may occur if, during production, starch breaks down to monosaccharides and disaccharides that are not used by the yeast but are retained in the final product.

Much time and effort is spent on precisely measuring micronutrients within foods to ensure appropriate dietary guidance. It is hard to conceive that discussions involving recommendations for calcium could proceed if the calcium content of foods were estimated rather than analyzed or that scientists would use the measured iron content of foods to establish dietary guidance without determining its bioavailability. Because this same accuracy and precision are not available for sugars, use of food-composition data must acknowledge its critical limitations.

APPLICATIONS OF SUGARS INTAKE DATA

As stated previously, nutrient data serve many purposes. Most pertinent to the sugars discussion is the application of these data in developing dietary guidance and determining the effect of sugars on health. Because neither data source provides precise values, use of both intake and availability data for either purpose must be done judiciously.

Dietary guidance

In terms of establishing guidelines, as stated by Robbins (44), "Many different dietary patterns can be compatible with a given set of dietary goals." This philosophy is reflected in the dietary reference intakes for macronutrients (19). The maximal intake of 25% of energy from added sugars (as defined by the USDA) is based on the ability of the US diet to provide sufficient intakes of essential micronutrients and allows flexibility in food selection and patterns.

The 2000 *Dietary Guidelines for Americans* recommend choosing beverages and foods to moderate the intake of sugars (45). Although the sugars statement has undergone numerous revisions, consumers have been given specific advice regarding sugars intake for many years (46, 47). The first USDA food guide (published in 1916) suggested that 10% of energy should come from sugars and sugary foods (other than those in milk and fruit) (46). In contrast, the 1977 *Dietary Goals for the United States* (48) suggest an intake of 15% of energy from sugars. After the establishment of the term *added sugars*, the Food Guide Pyramid suggested intakes ranging from 6% to 10% of energy (a range of 6–18 tsp, or 24–432 g, depending on the calorie content) from added sugars (49).

Whereas the contribution of added sugars to total energy recommended in the dietary reference intakes was determined to provide adequate micronutrient intakes, the USDA did not intend the 6–10% of energy to be cited as an optimal amount of added sugars. The USDA's goal was to meet nutritional needs and balance calories while not exceeding the consumption levels of added sugars reported at that time (8, 49). The USDA performed the following calculations in setting intake ranges: specified nutritional goals [based on the 1989 *Recommended Dietary Allowances* (50)] were met by determining the number of servings for each nutrient-containing food group (eg, grains, meats, milk, fruit, and vegetables). Three levels of energy (1600, 2200, and 2800 kcal) were set to encompass the 1300–3000 kcal range for meeting the energy needs of nearly all Americans. The energy content of foods was determined by using the lowest fat-containing food from each food group form (eg, fat-free milk). This procedure resulted in a range of 1220–1990 kcal. Next, the goal of 30% of energy from fat was applied at each established calorie level. After the calories provided by total fat were subtracted, the remaining calories could be obtained from a variety of food choices, including foods with added sugars (8). A person who chooses a diet containing 25% of energy as fat could consume more added sugars, whereas a person who chooses to use alcohol would need to reduce the intake of added sugars.

Health effects

Throughout recent years, intakes of sugars were suggested to be associated with a variety of health issues. After much deliberation, many alleged adverse health effects of sugars were determined to be without scientific foundation (51), and sugars alone were determined not to be associated with obesity, hyperactivity in children, diabetes, and coronary heart disease (16). However, these issues have continued to be a concern since then (52). During discussions by the 2000 Dietary Guidelines Advisory Committee, several assumptions and expectations regarding the effect of the guideline on chronic diseases (specifically obesity) were implied. An exploration of these assumptions and expectations would be helpful when discussing the potential effects of suggesting limiting intakes of sugars. Without such examination, it becomes difficult to test the hypothesis that overconsumption of added sugars causes obesity (22, 34, 53–58). For the ensuing points, the term *added sugars* will be used and comparisons with similar issues regarding intakes of fat will be made (59, 60).

The central assumptions and expectations in the sugars dialogue are as follows.

1) If added sugars intakes are reduced, individual persons or population groups who consume too much will automatically make healthier food choices and improve diet quality. This did not occur when consumers were advised to reduce their intake of total fats. The initial increase in the number of available palatable lower-fat foods was not accompanied by an increased use of these products across the population.

2) If individual persons or population groups reduce their consumption of added sugars, their total energy intake will automatically be reduced. The methods and foods consumers choose to reduce added sugars may or may not lead to total energy reduction, as was observed when lower-fat food choices were analyzed (59, 61).

3) If individual persons or population groups reduce their consumption of added sugars, a reduction in body weight will automatically occur. Even the use of palatable lower-fat foods to replace full-fat foods does not by itself ensure a reduction in body weight (62).

4) Through the use of availability data, it appears as if all consumers have equal intakes of sugars. This implies that every American needs to reduce their intake of sugars. When similar advice was given to consumers about fat, some persons interpreted it to mean that they should eliminate all fats from their diets, which led to dangerously low intakes.

5) The intake of added sugars is worse than that of natural sugars. Physiologically, this is inaccurate.

For most Americans, dietary guidance implies behavior change. However, a change in dietary behavior is not a simple process, as most nutritionists and health professionals know. Even those persons most motivated to change their behavior are challenged by the difficult reality of doing so. Strategies to lose weight might involve a reduction in the intake of sugars, but other lifestyle changes (eg, an increase in physical activity and a decrease in the portion sizes of foods consumed) are necessary as well.

Consumer attitudes toward dietary advice and sugars

Although consumers frequently use the term *sugar* to describe both table sugar (sucrose) (9) and most other commercially common caloric sweeteners, it is assumed that they know which foods contain sugar, sugars, and added sugars. In the Diet and Health Knowledge Survey portion of the CSFII survey, 2 questions were asked that related directly to sugars (15). Regarding the intake of sugar and sweets, 31.0% of men and 37.7% of women said that they consume too much, whereas 56.4% of men and 53.8% of women said they ate about the right amount. When asked to rate the perceived personal importance of using sugars in moderation, 45.0% of men and 56.0% of women answered that it was very important; ≈33% considered it to be somewhat important.

A more recent survey (2002) asked shoppers to rate their level of concern about the nutrient content of what they eat (23). Of the 870 shoppers surveyed, 18% said that they were concerned about the sugar (ie, sucrose) content of their diet; this value was double that reported in a similar survey conducted in 2000. When asked about eating sugar, 24% claimed that they were consuming less to ensure a healthy diet, a 10% increase from 1999.

In 14 focus groups conducted to assess understanding of the concepts and messages presented in the 2000 *Dietary Guidelines*, most consumers were under the impression that intakes of sugars should be limited (63). This belief is confirmed by a study in which 20 women were asked to classify specifically which sugars-containing foods belonged in a healthy diet (64). Response choices ranged from "always fit" to "never fit." Fruit, fruit juice, fruited yogurt, chocolate milk, low-fat baked goods, and granola bars were more likely to be classified as "always fit" foods. "Never fit" foods included soft drinks, candy, presweetened cereal, chocolate, cake, and cookies.

The *Dietary Guidelines* focus groups identified foods that contain added sugars along with those that were particularly high in added sugars (including soda, juice drinks, ice cream, and cereals). In contrast, the findings from a qualitative study of almost 40 women indicate that these women found "added sugars" to be confusing and that the phrase "food and beverages with added sugars" appearing in the text of the 2000 *Dietary Guidelines for Americans* did not accurately describe sweet foods and drinks to consumers (65). Interestingly, when the participants were asked to choose from a variety of descriptors of sugars-containing foods, "sweets" was the term that they most clearly defined as being foods such as candy, cookies, chocolate, pies, and cake, whereas "foods that contain sugar" were identified as foods such as cereal, soft drinks, and desserts. Sugars was interpreted to mean different types of sugar (eg, brown and white). In summary, these women were not able to come to a consensus as to which one term would encompass the wide variety of foods containing sugars as ingredients, although these same consumers suggested that sweet foods would indicate a wide variety of sweet-tasting foods with the fewest negative connotations.

In a study of > 1000 women, 58% reported feeling some level of guilt when eating sweet foods and sugars (66); slightly > 10% felt guilty everyday, whereas ≈50% felt guilty at least once per week. Mothers with children younger than 12 y strongly agreed that banning sweets could backfire. They concurred with the idea that when kids are allowed some sweet treats they will be less likely to overconsume them. Clearly, these consumers had conflicting ideas regarding the consumption of sugars-containing foods, but their feelings are supported in the literature (67).

CONSUMPTION OF SUGARS

A display of data reflecting intakes of sugars appears in **Table 5**.

TABLE 5
Intakes of sugars data[1]

Data source and measurement	Author	Population	Amount	Mean percentage of energy
NHANES III				
Total sugars (sum of 6 added and naturally occurring sugars)	Keast et al (68)	Adults (obese compared with nonobese)	None given	24% (range: 22% for men aged ≥51 y to 26% for women aged 19–30 y) Obese adults (BMI ≥ 30) had a lower percentage of energy from total sugars than do nonobese adults (22.9 ± 0.3 compared with 23.8 ± 03%)
Energy-dense, nutrient poor foods (desserts and sweeteners, including sugar, candy, syrup, sweetened carbonated, and noncarbonated beverages)	Kant (22)	Adults ≥ 20 y	None given	Total population: 8.6% for desserts; 9.4% for sweeteners; females: 8.7% and 9.4%, respectively; males: 8.4% and 9.3%
1994–1996 CSFII				
Gram equivalents[2]	Guthrie and Morton (54)	Adults, children, and adolescents	82.2 g equivalents average intake (range: 44.9 for females aged ≥65 y to 141.8 for males aged 12–17 y)	15.8% (range: 11.6% for men aged ≥65 y to 20% for all adolescents)
Sugars and sweets	Table 9.6 (1-d intake) (15)	Total, adults, children and adolescents	Total population: 25 g	None given
Beverages	Table 9.7 (1-d intake) (15)	Total, adults, children, and adolescents	Fruit drinks and ades: total population (95 g/d); females (range: 37 g for ages >60 y to 134 g for ages 12–19 y); males (range: 30 g for ages >70 y to 157 g for ages 12–19 y) Regular carbonated beverages: total population (253 g/d); females (range: from 47 g for ages >60 y to 351 g for ages 20–29 y); males (range: 63 g for ages >70 y to 583 g for ages 12–19 y)	None given
Fruit juices	Table 9.3 (1-d intake) (15)	Total, adults, children, and adolescents	Citrus: total population (60 g/d); females (range: from 35 g for ages 30–39 y to 67 g for ages 12–19 y); males (range: 54 g for ages 60–69 y to 93 g for ages 20–29 y) Noncitrus and nectars: total population (27 g/d); females (range: from 7 g for ages 50–59 y to 39 g for ages 6–11 y); males (range: 11 g to 60–69 y to 36 g for ages 6–11 y)	None given
Added sugars	Krebs-Smith (56)	Total, adults, children, and adolescents	Total population (20.5 tsp); children (24.1 tsp); adults (19.2 tsp); females (range: from 11.5 tsp for ages >60 y to 24.6 tsp for ages 12–19 y); males (range: 14.8–35.3 tsp for same age groups)	Total population (15.8%); children (18.6%); adults (14.8%); females (12.5–20.2% for same age groups); males (11.6–20.1% for same age groups)
Food guide pyramid servings for added sugars	Table 6 (2-d average) (15)	Total, adults, children, and adolescents	Population (20 tsp carbohydrate equivalents)[3]; females (range: from 11.1 tsp for ages >70 y to 23.5 tsp for ages 12–19 y; males (range: from 13.9 tsp for ages >70 y to 34.2 tsp for ages 12–19 y)	Population (15.7%); females (range: from 12.4% for ages 60–69 y to 20.2% for ages 12–19 y); males (range: 11.9–20.0% for same age groups)
USDA, ERS				
Per capita availability of caloric sweeteners, 1998	ERS (69)	Total US population, including armed forces	152.8 lb, dry basis (67.0 lb refined sugar + 62.8 lb high-fructose corn syrup + 21.7 lb nonfructose corn sweeteners)	None given

(Continued)

TABLE 5 (*Continued*)

Data source and measurement	Author	Population	Amount	Mean percentage of energy
Per capita availability of caloric sweeteners, 1999	ERS (7)	Total US population, including armed forces	153.2 lb, dry basis	None given
Per capita availability of caloric sweeteners, 2000	ERS (7)	Total US population, including armed forces	150.1 lb, dry basis	None given
Per capita availability of caloric sweeteners, 2001	ERS (70)	Total US population, including armed forces	148.0 lb, dry basis	None given

[1] NHANES III, third National Health and Nutrition Examination Survey; CSFII, Continuing Survey of Food Intakes by Individuals. 1 tsp = 4 g; 1 lb = 0.45 kg.

[2] Added sweeteners comparable in carbohydrate content with 1 g sucrose.

[3] One teaspoon of added sugars is defined as the quantity of a sweetener that contains the same amount of carbohydrate as 1 teaspoon of table sugar (sucrose).

Food intake data

The 1994–1996 CSFII provides an array of information regarding sugars intake through a series of published tables (15). These tables present intakes by food groupings; by age, sex, ethnicity, income and education; and by individual foods and provide a panorama of information. Furthermore, the relative contribution of added sugars by food category was determined on the basis of this survey (54); for details, *see* the article by Murphy and Johnson (52).

The reported mean population intake of added sugars is ≈80 g, which contributes a mean of 15.8% of energy (15). Mean intakes for children aged < 12 y were < 19% of energy, increased to ≈20% for adolescents, and then decreased throughout adulthood. For men and women, respectively, mean intakes were 16.8% and 17.9% for those aged 18–34 y, 14.4% and 14.9% for those aged 35–54 y, 12.7% and 12.8% for those aged 55–64 y, and 11.6% and 12.4% for those aged ≥65 y.

Per capita food availability data

The per capita availability of caloric sweeteners from 1998 to 2001 can be found in Table 5 (69) and **Table 6** (71). The increase in the availability from 1970 to 1995 appears to have leveled off from that point to 2002. In addition, a shift in specific sweeteners occurred, with the per capita availability of cane and beet sugar decreasing from ≈100 lb (≈45 kg)/y to its present level of ≈67 lb (≈30 kg)/y and that of corn-based sweeteners increasing from ≈19 lb (≈8.6 kg)/y to nearly 85 lb (≈38 kg)/y (69).

FUTURE CONSIDERATIONS

To obtain a more accurate picture of intakes of sugars, a convergence of individual intake data with economic availability estimates should be attempted. This could be accomplished in 3 ways: by *1*) improving methods for determining intakes to reduce underreporting, *2*) accounting for manufacturing losses and other nonfood and nonalcoholic beverage uses of sugars to reduce overestimation, and *3*) measuring the exact sugars content of foods rather than obtaining data from calculations from recipes. Improved methods for determining intakes could be directed specifically toward the known biases in underreporting (eg, feelings of guilt and embarrassment). Inclusion of behavioral psychologists and cultural anthropologists into the team designing survey questions would add critical insight. Finally, attempts should be undertaken to propose and adapt common terms used by regulators, scientists, manufacturers, and consumers alike. Agreement about which foods and ingredients to include and exclude would require commitment from all parties involved. Such efforts would open the path for better understanding, communication, and health.

CONCLUSIONS

Examination of current data suggests that the rigor given other nutrients is lacking in regard to sugars, specifically concerning the accuracy of measurements, reported intakes, and estimates of availability. Given this lack of clarity, discussions concerning the health effects of sugars must be framed rationally and be supported by scientific evidence. Underlying assumptions and expectations related to specific nutrient and food choices must be consciously made with the consumer in mind. For consumers to implement dietary recommendations, they must be provided with clear, relevant messages that are based on quality evidence. Such messages are critical to maintaining the trust and confidence of

TABLE 6
Availability of caloric sweeteners between 1970–1974 and 2000 based on food supply data[1]

Caloric sweeteners	1970–1974	1975–1979	1980–1984	1985–1989	1990–1994	1995–1999	2000
Not adjusted for loss and waste							
(tsp)	37	37	36	39	42	45	45
(g)	148	148	144	156	168	180	180
Adjusted for losses and waste from retail, food service, and home use							
(tsp)	26	26	26	28	30	32	32
(g)	104	104	104	112	120	128	128

[1] Adapted from reference 71. Values were calculated as teaspoons per capita per day and converted to grams. The percentage change from 1970–1974 to 2000 was 23% for both unadjusted and adjusted losses.

consumers in those who develop the recommendations and in those who deliver them.

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