Commentary

Fluid Energy—Where’s the Problem?

RICHARD D. MATTES, PhD, MPH, RD

The position that energy derived from a fluid may hold different appetitive and dietary implications than energy obtained from a solid food is more than a quarter century old (for examples, see references 1 and 2). The preponderance of early trials revealed energy-yielding fluids did not elicit strong reductions of hunger or compensatory dietary responses either in an absolute sense or relative to solid foods matched on properties, including energy, macronutrient composition, and palatability. The vehicles used in these studies ranged from clear beverages to dairy-based formulas to soups (3).

The preponderance of early trials revealed energy-yielding fluids did not elicit strong reductions of hunger or compensatory dietary responses either in an absolute sense or relative to solid foods matched on properties, including energy, macronutrient composition, and palatability. The vehicles used in these studies ranged from clear beverages to dairy-based formulas to soups (3).

Further investigation has helped to clarify and refine understanding of the issue. The original view that different types of fluids elicit comparable appetitive and dietary effects is no longer tenable. Clear distinctions are emerging, making it useful to classify fluid foods into four categories based on their effects on satiety and energy balance. Recognition of these product differences is essential to move understanding forward because negating the effect of one category of fluids (eg, beverages) by citing evidence from another (eg, soups) may misdirect attention from real issues.

**FLUIDS WITH STRONG SATIETY VALUE THAT MAY NOT PROMOTE POSITIVE ENERGY BALANCE**

Some fluids, such as soups, have high satiety value and elicit strong dietary compensation. The satiation/satiety properties of soups are consistently observed in acute feeding trials (4-8), although the mechanism has not been firmly established. Attributes such as energy and nutrient composition, chemosensory properties, energy density, temperature, and volume do not appear responsible because matching soups to solid foods on these properties does not eliminate differential responses (7,8). One feature that distinguishes soups and beverages is the cognitive impression they impart to consumers (7,9-11). It is well established that expectations may alter appetite ratings (12,13) and merely labeling a beverage a soup enhances the appetitive response it elicits (8).

**FLUIDS DESIGNED FOR STRONG SATIETY VALUE YET MAY PROMOTE POSITIVE ENERGY BALANCE**

Another category of dietary fluids is designed to have high satiety value, yet these are widely used to promote weight gain in those challenged to preserve body weight, such as elderly persons or various clinical populations (eg, patients with cancer or human immunodeficiency virus/acquired immunodeficiency syndrome) (17-19).

Meal replacement beverages are an example of fluids effective in this capacity in part because their satiation/satiety value is still lower than that of a solid food. More energy can be consumed in an eating occasion with these products and their ingestion is less likely to replace another eating occasion. The rationale for maximizing the satiety value of these products does not stem from this use, but rather for their application in energy-restricted diets to promote weight loss or maintenance of lower body weight. They can be effective for this purpose (20), but it is not clear that their satiety value is the functional property. Their incorporation into controlled feeding regimens may be the critical component.

**FLUIDS WITH LIMITED SATIETY VALUE YET MAY NOT PROMOTE POSITIVE ENERGY BALANCE**

A third type of fluid has low satiety value, but despite this and its high energy content, exerts limited influence on body weight. This group is typified by alcohol, when ingested in moderation. Excessive consumption results in alterations of behavior and physiology that are beyond the present scope of consideration. When ingested as an aperitif, alcohol augments hunger (21) and diminishes satiation (22,23). It also elicits a weak compensatory dietary response (24), so energy intake is increased. The positive energy balance promoted by alcohol has strong support in the epidemiologic (25-29) and intervention (24,30) literatures and occurs in men and women, young and elderly, as well as light and heavy consumers.
FLUIDS WITH WEAK SATIETY VALUE THAT MAY PROMOTE POSITIVE ENERGY BALANCE

The fourth class of energy-yielding fluids would include those that have low satiety value and promote positive energy balance. This group includes beverages and, most notably, energy-containing clear fluids (eg, soda, specialty teas and coffees, sports drinks, and some fruit juices). It is an especially important grouping because of their considerable contribution to daily energy intake. The work by Storey and colleagues (44) reported on p 1992 in this issue of the Journal indicates they account for approximately 16% to 20% of total energy for individuals aged 6 to 60 years. These new data are important, not only because of their documentation of high levels of consumption, but also for identifying variability associated with sex, age, and ethnicity. The weak satiety effects of clear beverages have been amply documented (9,10,45-47). It holds in younger and older populations and different ethnic groups (9,10,46,48-51). Importantly, it occurs for beverages with different macronutrient compositions. In particular, the stronger satiety value of protein noted in solid foods is ameliorated or lost in fluid products (52), even with substantive loads (53). Higher energy intake has also been reported among consumers of gourmet teas and coffees where fat may be a substantive source of energy (54), as well as dairy products with higher protein content (11). Whereas soda is the single largest source of energy in the US diet (55), and its primary source of energy is carbohydrate, the totality of the literature suggest the amount or particular form of sugars may not be as important as the fluid medium in determining the effects of these beverages on energy balance. There is a direct relationship between viscosity and hunger suppression (56) and a meta-analysis revealed a graded dietary compensation response to ingestion of fluid, semi-solid, and solid foods (3) with clear liquids eliciting no compensation. Moreover, there is limited adaptation with chronic use (47).

Isolated trials have failed to note a differential effect of solid and fluid foods matched on energy content, but these exceptions may stem from methodological issues. For example, they have been noted under atypical conditions where food was delivered by pump (57). Strong compensation for fluids has also been reported in very young children (58,59). However, they display more precise compensation generally during their early years and this is lost by about age 5. Thus, extrapolation of this case to adolescents, adults, or elderly people is uncertain. Another exception entails designs where appetite is measured following ingestion of large loads (eg, 710 mL), use of foods not customarily consumed at the time of day testing was conducted (midmorning snacking is uncommon) (60), testing when participants were not hungry (thus, potentially creating floor effects), and assessments at intervals shorter than normal intermeal intervals (eg, 20 minutes or 2 hours) (61). Actually, the failure to note a differential effect of fluid vs solid foods on appetite under such conditions also speaks to the lack of sensitivity to fluid loads because they had greater levels of other attributes associated with satiety such as volume and weight (almost eightfold).

The nutritionally important question is whether or not these products exert an effect on energy balance that differs from comparable solid items. The argument that they do is based on literature documenting that the relationship between their ingestion and body weight or body mass index (BMI) is temporarily logical, consistent, strong, specific, and coherent. Although the BMI of the population has probably been increasing for over 250 years (62), a sharp rise occurred about three decades ago. This was associated with a 150 to 300 kcal/day increase of daily energy intake (63). During this time, the number of servings and serving sizes of beverages increased (63). Daily energy derived from beverages increased from 2.8% to 7.0% and they are estimated to have contributed energy equal to about 50% of the total increment in energy intake (63). Thus, the temporal trends support an association. The consistency of an association between beverage consumption and BMI is supported by evidence that it holds in adults and children, males and females, and different ethnic groups (50,51,64-70). Furthermore, an analysis of data from the 1994 Continuing Study of Food Intakes by Individuals revealed a dose–response relationship between beverage and energy intake in adolescents (49). The strength of association is supported by multiple controlled animal model studies (for examples, see references 71 and 72) as well as observational and intervention trials with human beings documenting a weaker compensatory dietary response to fluids compared to solids and/or a direct relationship between clear beverage consumption and BMI (3,9,51,65,66,68,70,71,73,74). Evidence indicating the relationship is specific stems from findings that adding caloric beverages to the diet leads to elevations of energy intake and weight gain (65,75) while their reduction or elimination from the diet results in lower energy intake and BMI (67,76,77). A within-subject intervention trial directly contrasting responses to fluid and solid foods showed weight gain only with the fluid load (65). Furthermore, a controlled trial with humans...
has demonstrated non–energy-containing fluid ingestion is not associated with increased energy intake or body weight, but both increase with the addition of an energy source to the beverage (78). This is expanded in the study by Flood and colleagues (79) reported in this issue of the Journal (p 1984) who observed the inclusion of larger portions of energy-yielding beverages in a meal led to increased energy intake due to a lack of adjustment in food intake. A weak compensatory dietary response to beverages has been reported within meals (11) and over days (69,70).

Collectively, these points lead to a coherent argument that beverages may be contributing to positive energy balance and the increasing incidence and prevalence of overweight/obesity. However, another important element is identification of plausible mechanisms. Why might energy-yielding fluids exert different effects on energy balance than solid foods? To date, much of the work on this topic has focused on establishing the phenomenon with limited exploration of mechanisms. Feeding is guided by environmental and physiological (eg, cognitive, oro-sensory, digestive, metabolic, endocrine, and neural) influences. Differential responses may be posited at each level. Environmentally, portion sizes of beverages have increased markedly (80,81), they are among the least expensive sources of energy, and are a meal component that is provided in unlimited quantity in most commercial restaurants. Beverages have lower expected satiety value, lower demand for oral processing, shorter gastrointestinal transit times, and the energy they contain has greater bioaccessibility and bioavailability. Each of these attributes has been associated with weaker effects on appetite and dietary compensation (65,82-89). The absolute and relative importance of these properties, and others, has not been established, but warrants exploration. An additional possibility is that clear beverages alter diet composition and may displace components that help regulate intake. A popularly cited example is milk. However, milk also seems to elicit a weak compensatory dietary response (11).

**IMPLICATIONS FOR FUTURE RESEARCH AND CLINICAL PRACTICE**

Recognition of the differences in the appetitive and dietary effects of various energy-yielding fluids should help clarify their health implications and guide future research. To isolate the effects of the medium (ie, fluid) rather than some other physical (eg, solid form) or chemical (ie, macronutrient) property on appetite or diet, it is essential that the identical foods be used. Studies comparing the appetitive responses to fruit juice and the same whole food (45,90) approach this standard and have noted weaker satiety effects for the fluid form. Still, better-controlled studies are required because these contrasts do not account for dietary fiber, a known satiety factor. It will also be important to explore and control the effects of thirst on appetite. Although the physiological systems controlling these sensations are distinct, fluids are increasingly ingested as food/meal replacements. The acute and long-term dietary consequences of this substitution are unknown, but based on the literature cited here, may be expected to increase energy intake.

Taken together, it appears that clear beverages are especially problematic for energy balance. They are widely consumed, elicit weak compensatory dietary responses, promote positive energy balance, and increase body weight. Some have recommended their use be restricted, especially by children and adolescents. This has prompted the exploration or passage of regulations on the availability of sweetened carbonated beverages and sport drinks in schools (eg, California bill SB965). Currently, more than 60% of states are considering or have enacted legislation limiting sales of such products in schools or during school hours (91). It is often proposed that these products be replaced with more healthful beverages such as fruit juice (for an example see reference 92); however, the literature indicates these products are also problematic with respect to energy balance. So, the efficacy of this approach, with respect to weight management, is questionable. An alternative is to replace the energy-rich versions with non–energy-containing substitutes. This would permit continued consumption with limited affect on energy intake. Whether such an approach has negative implications for overall diet quality is a separate but meritorious issue. Alternatively, clear beverages can continue to be ingested at their current level if a conscious effort is made to offset the energy contributed by this source through reductions of food intake. The practicality, efficacy, and nutritional implications of this approach are also not known. Clearly there is a need for objective study of these options. The two articles in this issue of the Journal provide useful insights toward this end. They document levels of consumption by different subgroups of the population (44) and the effects on energy balance of incorporating different serving sizes of energy-containing beverages into meals (79).

**References**


9. Tournier A, Louis-Sylvestre J. Effect of the physical


61. Almiron-Roig E, Flores SY, Drewnowski A. No difference in satiety or in subsequent energy intakes between a beverage and a solid food. *Physiol Behav*. 2004;82:671-677.


77. Ebbeling CB, Feldman HA, Osganian SK, Chomitz VR, Ellenbogen SJ, Ludwig DS. Effects of decreasing sugar-sweetened beverage consumption on body
89. Wisker E, Feldheim W. Metabolizable energy of diets low or high in dietary fiber from fruits and vegetables when consumed by humans. J Nutr. 1990;120:1331-1337.