

# A short history of beverages and how our body treats them

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## Summary

Numerous studies have demonstrated that beverages containing sugar, high fructose corn syrup (HFCS) or alcohol are handled differently by the body than when sugar or HFCS are incorporated in solid foods and as a result the overall caloric intake from solid food does not adjust to account for the calories in these beverages. A consideration of our evolutionary history may help to explain our poor compensatory response to calories from fluids. This paper reviews the history of eight important beverages: milk, beer, wine, tea, coffee, distilled alcoholic beverages, juice and soft drinks. We arrive at two hypotheses. First, humans may lack a physiological basis for processing carbohydrate or alcoholic calories in beverage because only breast milk and water were available for the vast majority of our evolutionary history. Alternatives to those two beverages appeared in the human diet no more than 11 000 years ago, but *Homo sapiens* evolved between 100 000 and 200 000 years ago. Second, carbohydrate and alcohol-containing beverages may produce an incomplete satiation sequence which prevents us from becoming satiated on these beverages.

**Keywords:** Beverages, caloric compensation, water.

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## Introduction

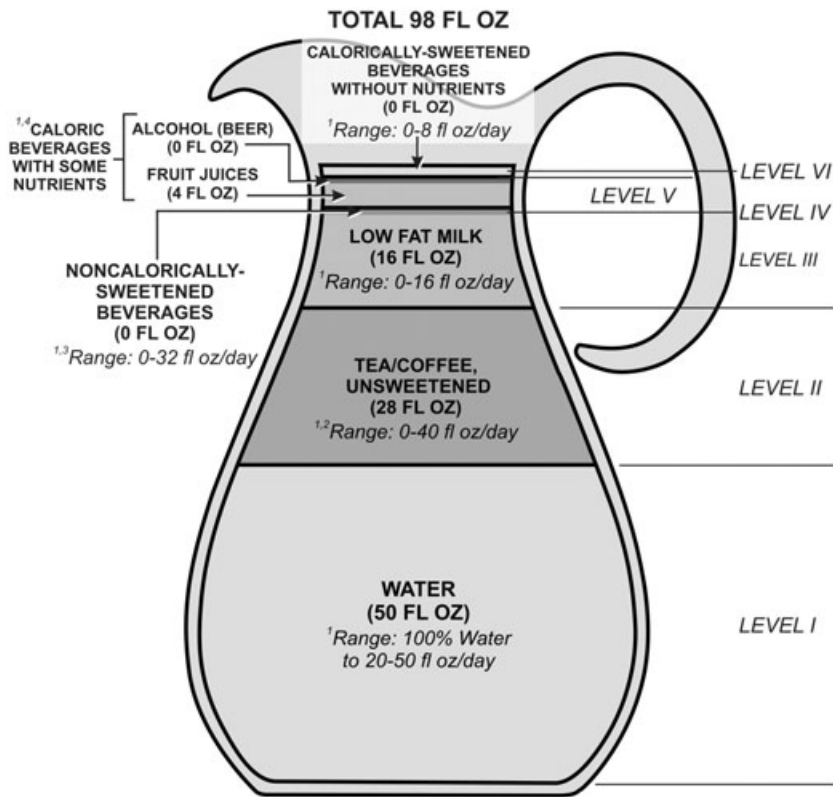
The recent publication of a Beverage Guidance proposal has increased the discussion of beverages and their health benefits. An extensive set of studies show that consumption of some calorie-rich beverages does not reduce intake of solid food to maintain energy balance. The net result is that when beverages containing sugar, high fructose corn syrup (HFCS) or alcohol are consumed, the total caloric intake from solid food does not adjust appropriately (1–3). This is true for some beverages, but may not be true for others. This review will attempt to put this issue into perspective. It consists of three parts. The first will present the current pattern of beverage consumption and outline the trends over the past 30 years. The second part will explore the historical appearance of beverages currently used by humankind. The final section will discuss the biological differences between digestion of beverages and solid foods.

## Current beverage consumption patterns

### US patterns of beverage consumption

By 2004 each American consumed over 135 gallons of beverages other than water, or about 1.5 L d<sup>-1</sup> (see Fig. 1) (4). While limitations in the data obscure some long-term trends, it is clear that the beverages most strongly recommended by the Beverage Guidance Panel make up a shrinking portion of US beverage consumption. The Beverage Guidance Panel created a beverage hierarchy to guide consumption, with water as a first choice followed by calorie-free tea or coffee, then low-fat milk and soy beverages, non-calorically sweetened beverages, calorie-containing beverages with some nutrients, and finally sugar or HFCS sweetened beverages (5). See Fig. 1 for this group's recommended beverage pattern.

While consumption of healthful beverages is falling, consumption of the most unhealthy beverages is strong. Both



**Figure 1** Suggested beverage consumption patterns (10% of energy from beverages) for a person with a 2200 kcal energy requirement per day. Footnote: The values of 50, 28, 16 and 4 fluid ounces are shown for illustrative purposes only and that the total should sum to 98 fluid ounces, as shown at the top of the figure. 1. The suggested range for each beverage from panel. 2. Range: caffeine is a limiting factor up to 400 mg d<sup>-1</sup> or about 32 fl oz d<sup>-1</sup> of coffee (can replace water). 3. Can substitute for tea and coffee with the same limitations regarding caffeine. 4. 100% fruit juices 0-8 fl oz d<sup>-1</sup>, alcoholic beverages 0-1 drink per day for women, and 0-2 drinks per day for men, whole milk 0 fl oz d<sup>-1</sup>.

milk and coffee consumption are currently less than half of their historical maxima. Tea consumption remains low, although largely unchanged. In contrast, regular soft drinks are the most popular beverage in the USA, consumed at a rate of over 35 gallons per person per year. Beverages sweetened with HFCS now account for 80% of added sugars in the US diet (6). The second most popular beverage is beer which falls into the less healthful 'caloric beverages with some nutrients' category.

One positive trend is that low-fat milk now makes up two-thirds of milk consumption in America (7). Also encouraging is the fact that consumption of regular soft drinks is trending downwards, while diet soft drinks are the fastest growing beverage category. However, research indicates that the fall in regular soft drink consumption may be an artifact of beverage classification (8). Numerous new sweetened beverages such as energy drinks have been introduced which may be cutting into the market share of soft drinks without improving the nutritional profile of beverage consumption in America. Figure 2 presents the longer-term US beverage trends.

### Global patterns of beverage consumption

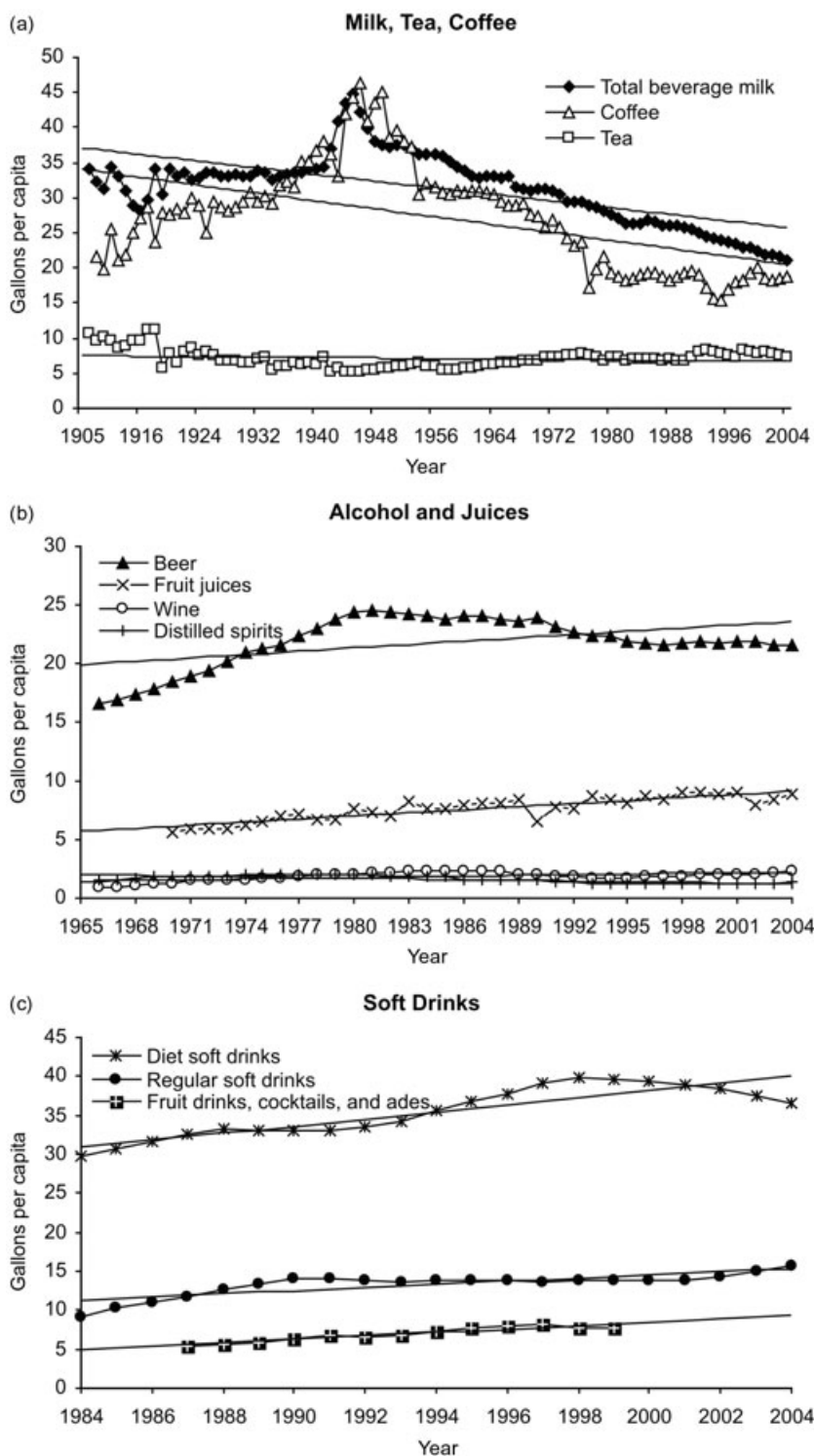
Globally, the availability of beverages tracked by the Food and Agriculture Organization of the United Nations (FAO) has grown more than 20% in the last 40 years (see Fig. 3)

(9). Over that same time period, the population of the world has doubled, indicating that the volume of beverages produced worldwide has grown 140%. That growth does not include soda or juice, although Coca-Cola products alone are consumed at a rate in excess of one billion drinks per day (10). The greatest increase has been in beer consumption, which has risen almost 5 gallons per person per year. That is followed by tea, which increased a little more than 4 gallons per capita per year. Wine and milk consumptions have both fallen worldwide, by three-quarters and 1.5 gallons per year respectively.

Tea remains the world's most popular beverage (consumed at a rate of more than 12 gallons per person) followed by milk and beer (at 11 and 8 gallons per capita per year respectively). Together, those three beverages make up more than three-quarters of the total of the beverages that FAO monitors. An increase in milk consumption in southern hemisphere nations has contributed to a shift in the types of milk produced (9).

### Historical introduction of beverages

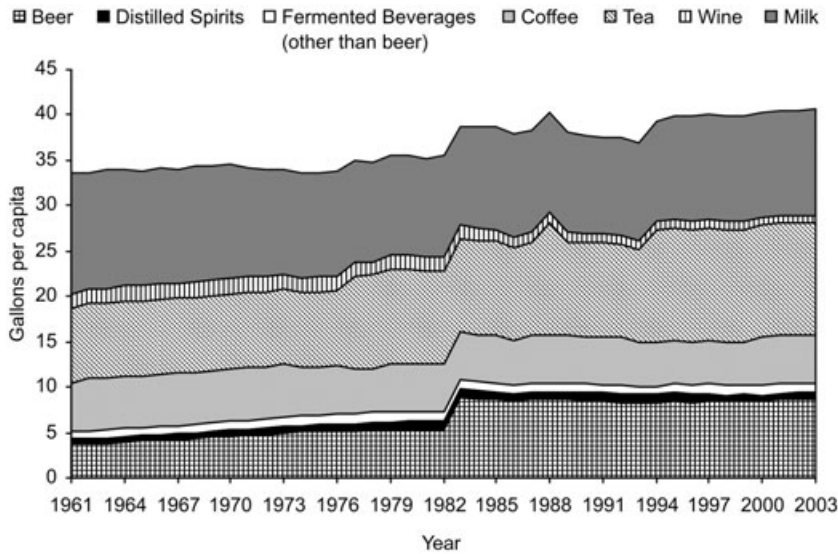
The genus *Homo* separated from other hominids between 2 and 3 million years ago, and *Homo sapiens* appeared between 200 000 and 100 000 years ago (11,12). For all but the last 11 000 years of that evolutionary history, the predominant beverages consumed were water and breast



**Figure 2** US beverage supply (with trend lines). Source: USDA Economic Research Service. *US per capita food consumption: Beverages (individual)*. 2005. <http://www.ers.usda.gov/data/foodconsumption/> (25 April 2006).

milk, which we will refer to as a ‘complete’ ‘beverage’ as it contains protein, fat, carbohydrates and water. Breastfeeding terminates in childhood, so, for the vast majority of human history, adults consumed predominantly water which provided no calories from beverages.

Figure 4 is a graph of the time when most major beverages entered the human food chain. The relatively recent addition of caloric beverages to the adult diet, considered in combination with the recent set of studies demonstrating weak caloric compensation for beverage calories (discussed



**Figure 3** World beverage supply. Source: Food and Agriculture Organization of the United Nations, FAOSTAT. <http://faostat.fao.org/> (accessed 22 May 2006).

in section three) may contribute to understanding part of the current epidemic of obesity. Humans have responded to the environment in which they have evolved over millions of years. We may lack a genetic basis for processing beverage calories because we evolved without being exposed to sugar-containing or alcoholic beverages after weaning. Alternatively, our processing of sugar-containing or alcoholic beverages may be confounded by the mechanism which developed for water consumption. Water, to which we have been exposed the longest, rapidly enters the intestine. That response helped ensure that water intake by early humans would not blunt the desire to eat simply because they had recently satisfied their thirst. This topic will be discussed further in the final section of this paper. Through an exploration of the history of major beverages in the human diet, this paper will consider the appropriateness of those hypotheses to explain the inadequate compensatory response to beverages containing sugar or fructose (e.g. HFCS) or alcoholic calories. We begin with animal milk, likely the first beverage consumed by humans other than water and breast milk, and proceed forward in time.

## Animal milk

### History

Determining when animal milk was first consumed is very difficult. First, because it could have been drunk directly from the teat of an animal, milk consumption does not require specialized equipment such as the presses used for wine grapes or the carboys used for beer, so archeological artifacts are less indicative of its history. Second, milk is not only drunk, but is also used to make butter, cheese, yoghurt and other fermented products. Those foods would have been much easier than milk to store and transport when containers for liquids were scarce and refrigeration was

non-existent (13,14). The earliest reliable record of dairy products is a tablet left by a Sumerian farmer in approximately 4000 BCE. The writing details herd size and cheese and butter production (13).

Ovines – sheep and goats – were probably the first animals domesticated and the first animals milked. The earliest evidence of domesticated sheep comes from about 9000 BCE in Iraq and Romania. Those nomadic herders were likely the first milk drinkers, although it remains possible that they kept their animals only for meat (15). Thus, 9000 BCE marks the earliest starting point for consumption of caloric beverages (see Fig. 3). The domestication of cattle most likely took place between the eighth and the seventh millennium BCE (15,16). There is solid evidence that milk was being consumed by about 2000 BCE (13).

One interesting feature of milk consumption is that only some human populations maintain the ability to digest lactose into adulthood. Those populations are typically described as lactase persistent. Genetics research demonstrates that the gene for lactase persistence arose between 5000 and 10 000 years ago in European populations and independently 6,000–7000 years ago in parts of Africa (17,18). The selective advantages of lactase persistence were enormous. It made a large supply of calories available to adults carrying the gene. Also, as humans migrated to colder climes, they exposed far less skin. As a result, they synthesized less vitamin D. Because vitamin D plays an important role in calcium absorption, people needed more calcium, and animal milk provided a ready supply to those who could digest it (19).

For some populations, milk had nutritional advantages beyond calories and calcium. Central Asian nomads got much needed vitamin C from mare's milk. Their diet had few fruits and vegetables, so they were at risk of scurvy.

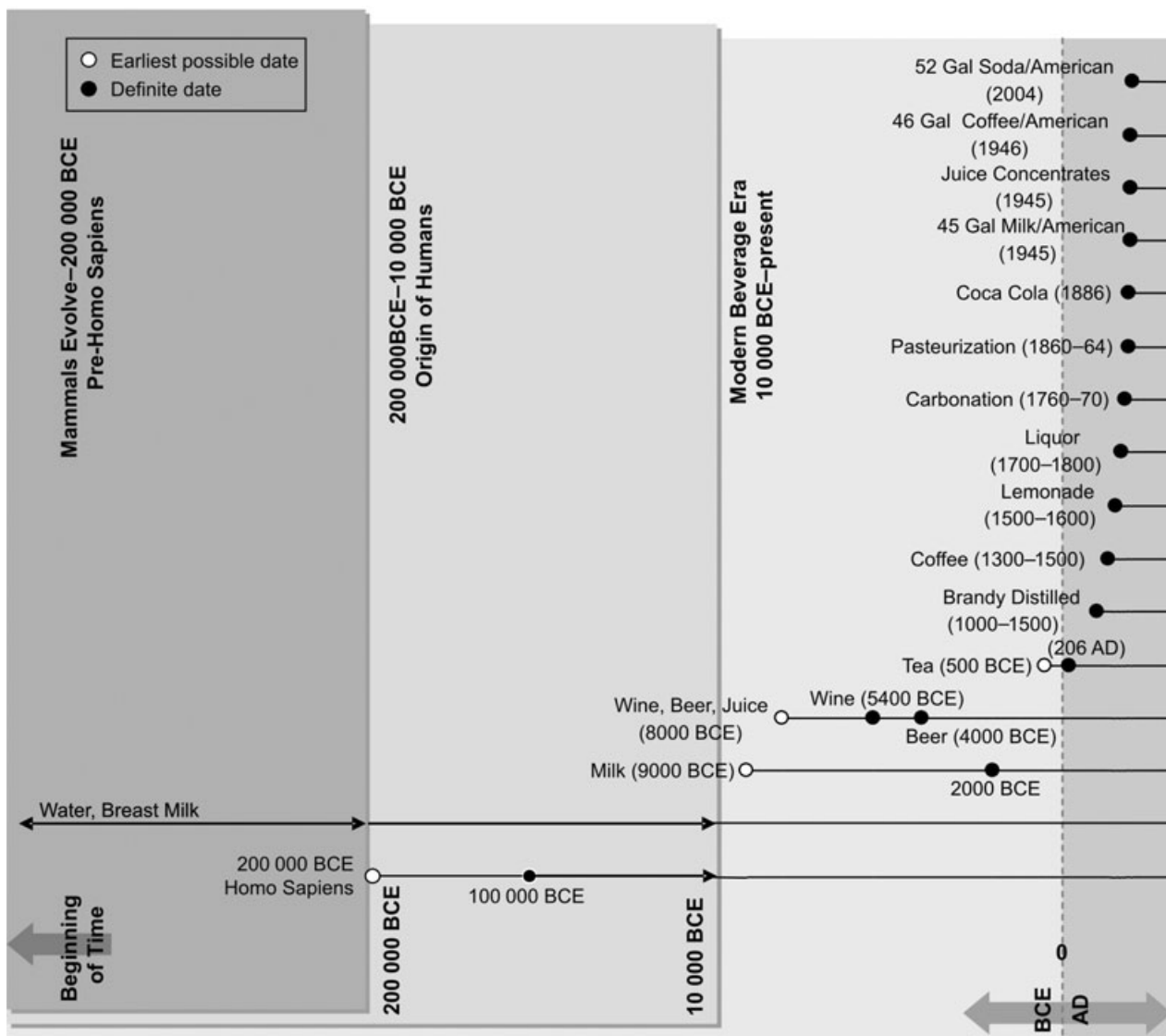


Figure 4 Beverage history timeline.

However, mare’s milk contains twice the vitamin C of human milk and four times that of a cow (15).

The development of pasteurization and other technologies greatly increased the safety of milk and allowed it to be marketed over a wider area. Before pasteurization milk consumption could transmit diseases, including cholera, polio, anthrax, scarlet fever, bovine tuberculosis and botulism (20,21). In the decade from 1908 to 1918, the per cent of London’s milk supply contaminated with the tubercule bacillus ranged from 7.4% to 11.6%. Milk could also cause brucellosis. This bacterium was present in 20–75% of raw milk in the 1930s in some regions of the world. By the 1930s, most milk in the UK and the USA was pasteurized. Milk was implicated in 17% of all typhoid epidemics. Still other diseases – such as cholera and salmonella –

occurred in milk because salespeople would use water to dilute milk in order to stretch their profits, but they often drew from contaminated sources (20).

Technological innovation helped to reduce the danger of transmission of infection by milk. Condensed and heat-treated milk, both marketed by the 1880s, reduced the dangers of milk (20,21) and prolonged its storage time on the shelf. Another important change that occurred in the late 19th century was the introduction of the stoppered milk bottle (20). Before bottling was introduced, milk was typically transported in containers which were open to debris and bacterial contamination (20). Material shortages during World War I helped to launch the use of paper cartons which, along with plastic jugs, remain popular today (22).



The popularity of milk in the USA peaked in the 1940s. US per capita milk consumption reached 45 gallons per person in 1945, but since then it has steadily fallen. In 2004, per capita annual consumption was 21 gallons (4).

#### *Modern trends*

Milk is increasingly being tailored to compete with beverages such as soft drinks. Twelve-ounce plastic bottles of sweetened, flavoured milk are widely available. The smaller bottles are typically sold from vending machines, just like soft drinks (23). While low-fat unsweetened milk is also sold from some of the same machines, in a recent study of milk vending machines in schools, chocolate and strawberry milk outsold unflavoured milk by a margin of nine to one (24).

### Beer

#### *History*

As humans abandoned their hunter-gatherer migratory existence and established agricultural communities, two things happened. First, faeces and other wastes were concentrated near human settlements, causing water pollution. Second, farming made grain and other essential foodstuffs available in quantities which exceeded immediate needs. Brewing beer provided a ready use for that grain, and a valuable line of defense against the pathogens in water (25).

The earliest date proposed for beer production is 8000 BCE. Extensive archeological evidence of beer production and consumption dates from 4000 to 3500 BCE (26). Researchers have suggested that the first beer was a batch of porridge left to sit too long (13). The Sumerians are generally considered to be the first beer makers, but the Egyptians soon formalized the process, making a bread from sprouted, dried grains, then breaking the bread into water and allowing it to ferment (15,27).

Beer enjoyed a great deal of early popularity. As much as 40% of Sumerian grain may have gone to make beer (15). At all levels of society, Egyptians drank beer. Most people drank it daily, and it was a common offering to the gods (27). In part, that may have been because few other beverages existed: no tea, coffee, wine, liquor, juice, or water that was without bacterial contamination (15). Also, the appeal of intoxication in a world with few entertainment options must have been compelling.

Beer provided a valuable addition to the diet. It was an early nutritional supplement, composed of readily available starches and sugars, much like bread (26). It also could have provided various minerals, depending on the grain used and the soil, and valuable B vitamins (27).

Travel and empire carried beer from the Middle East to Europe and Africa, but brewing also began spontaneously in many different locales. The Incas, for example, made corn-based alcohols, as well as those based on manioc and peanuts (26).

The introduction of hops helped to prevent spoilage and extend shelf life of beer thus allowing broader marketing. Although hops first appeared in the 8th or 9th century, they did not gain widespread use until the sixteenth century (26).

#### *Modern trends*

Pasteurization reached the beer industry long before it was applied to milk. Anheuser-Busch, for example, began pasteurizing beer in 1872. The company adopted the technology, along with others such as refrigerated rail cars, in order to expand its market to include the entire USA (28).

### Wine

#### *History*

Wine may also have been produced as early as 8000 BCE. The earliest evidence of winemaking from domesticated grapes comes from Iran and is dated somewhere between 5400 and 5000 BCE (29,30). Like beer, the first winemaking was probably an accident. A little juice might have escaped from grapes stored in ancient vessels. In 2 or 3 days, natural yeasts would produce alcohol (31). In hot weather and with potable water in short supply, someone would have been bound to taste that 'juice'.

From Iran, wine spread throughout Mesopotamia (30). There were vines on the Nile by 3000 BCE. Viticulture was also introduced in Greece, and from there, wine spread throughout the Mediterranean and then inland up the Rhone river (30). The export of wine was a driving force behind the growth of the Greek sea trade which in turn spread Western culture (32). When Rome conquered Greece, the Romans imported many aspect of Greek culture, including wine making (32).

The Romans were among wines greatest enthusiasts. They drank it at nearly every meal and by itself, although they typically diluted it with water. As the Roman Empire expanded, they carried grape-growing and wine-making practices with them, as well as their habit of consuming alcohol at mealtimes (30). The importance of that Roman influence is still felt. In southern Europe, within what was the Roman Empire, wine predominates, and is typically drunk with a meal. In northern Europe, where the Roman influence was less pervasive, beer was more common, and is typically consumed separately from food (32).

After the collapse of the Roman Empire, wine's place in Christian ritual helped to maintain production through the instability that followed (30). Monasteries protected and refined the art of wine making during a period when vines were difficult to maintain in Europe because of social unrest, and winemaking was vanishing in the Middle East and North Africa because of the advance of Islam (30). (Monasteries also played a major role in beer-making, but, because of beer's wider geographical base and dependence

on annual rather than perennial ingredients, it was less vulnerable to social variation.) Eventually, the advance of Islam drove wine-making out of the areas where it first arose, but European expansion carried wine production throughout the world (25). Europeans brought wine making to the Americas, starting in Mexico and going southward to Peru, Chile and Argentina (30). Early settlers found their European grapes would not survive in North America, victimized by root-eating aphids, but they adapted to producing wine from native varieties (30).

### Distilled alcoholic beverages

Distillation first appeared in Mesopotamia around 4000 BCE (32). The process was used primarily in the manufacture of perfumes, but it represented a major step in alcohol production. Until distillation, the sugar in the ingredients produced the alcohol in the final product, but stills made it possible to concentrate alcohol further (33).

Sometime between 800 and 1300 AD, distillation was introduced in China and Europe (33). St. Patrick is said to have brought a still back to Ireland after proselytizing in Arab countries, but it could have been soldiers returning from the crusades (33). Although perfume helped create the still, alchemy became the driving force behind its use in Europe. Sometime between 1000 and 1500 AD, alchemists developed brandy while searching for the 'essence' of wine (33).

Liquor was perceived as healthy during that early phase, often called 'aqua vitae', the water of life (33). Nonetheless, drinking spirits did not really begin until the 16th century, and it only became common in the 18th (34). The Dutch, who had a robust sea trade, played a large role in spreading liquor consumption. They encouraged the distillation of brandy to reduce the size of their wine cargoes (34). The price of distillation fell in the 18th century, and liquor consumption spread throughout Europe and North America (34).

Liquor has a strong national identity, perhaps even more so than beer. Scotland and Ireland's whiskeys are so closely associated with the countries that the beverages are called simply 'scotch' and 'irish'. Britain has gin, America has bourbon and Mexico has tequila. Other beverages such as brandy and rum are not related to just one country, but rather to entire regions (Western Europe and the Caribbean respectively). Globalization has brought that wide, international selection into most developed world bars.

### Tea

#### History

Tea is the world's most commonly consumed beverage after water, but it was not always so (35). In fact, it was not even always a drink. The earliest consumers of tea – in Thailand,

Burma, Assam and south-west China – chewed or cooked the leaves of the tea plant, *Camellia sinensis* (36). The origin of tea drinking is legendarily attributed to the Chinese emperor Shen Nung who reigned around 2700 BCE. He is said to have discovered tea when the leaves blew into his boiling water. There is evidence that legend is likely untrue, although the infusion of hot water that we know today probably did originate in China and spread to surrounding countries (32,35). Tea was certainly present by the Han Dynasty (206 BCE–220 AD), and it may have been drunk by Confucius around 500 BCE (35). The two main varieties are black and green. Black tea is fermented while green is not (35).

Tea remained a primarily Chinese beverage until the 17th century when Europeans, especially the Dutch and British, began to trade for tea and ship it to a broader market (36). In 1699, British tea imports were around 6 tons. By the late 1700s, imports had risen to 11 000 tons, and the price of tea was only one-twentieth the 1699 price (32). The British appetite for tea was one of several factors which led to the Opium Wars, a pair of engagements which were highly destructive to China but which expanded the British access to tea (32,35,36).

The British also learned to produce tea themselves. They established a committee to investigate Chinese methods. About 170 years after the British began drinking tea, the Tea Committee demonstrated that green and black tea was from the same plant, a fact that the Chinese had managed to keep from British knowledge. The British research enabled them to establish their own large tea production centre in India in the mid-1800s (35). Vastly expanded production led to lower prices and increased consumption.

#### Modern trends

The next two revolutions in tea consumption occurred in America. Iced tea was probably invented in 1904 at the US World's Fair (it may have existed previously, but, if so, its availability at the Fair dramatically increased its visibility and popularity) (35). A few years later, in 1908, teabags were invented, increasing the convenience of tea consumption (35).

### Coffee

#### History

Coffee consumption originated in Africa, either in Ethiopia or across the Red Sea in Yemen (37,38). The earliest legends suggest a 9th century AD origin. Those early consumers often simply ate the beans, raw or after frying in butter. To the extent that coffee was steeped and drunk, it was probably made using green (unroasted) beans (38). 'Modern' coffee – roasted, ground and brewed – probably originated in the Yemeni city of Mokka during the late 14th or early 15th century (38). Coffee quickly found a place in

Muslim culture, and its power to keep devotees awake during all-night rituals was counted as a blessing (32,38). In fact, some traditions hold that the archangel Gabriel gave Mohammed the knowledge of coffee. In that scenario, coffee was seen as a heaven-sent replacement for alcohol, which was restricted (38). Certainly, the coffee house filled the same role in Muslim societies that taverns filled in European: a place to gather and talk (25).

The Ottoman Turks who ruled Yemen tried hard to ensure that coffee remained a strictly domestic product, even boiling any beans for export so that they would not germinate (39). Eventually, although, the spread of the Muslim religion carried coffee cultivation with it (38). Pilgrims to Mecca from India and Indonesia managed to bring home viable beans, expanding the geographical base of coffee cultivation (38).

The spread of coffee consumption followed a different path. Coffee drinking spread from Egypt to Istanbul in 1554. From there, coffee quickly conquered Europe. Coffee appeared in Venice in 1615, in France in 1644, in both England and Vienna in 1650, and by 1668 it had boarded a boat and traveled to North America (37,38). High taxes on coffee and their own South Asian expansion eventually turned the UK into a tea drinking country, but their initial embrace of coffee – like that of the rest of Europe – was passionate (38). Europeans added honey and milk to their coffee, and they vastly expanded the techniques for brewing (38).

In the 1700s, the French introduced coffee cultivation to Martinique, and it spread from there to South America (39). When American colonists came to view tea as a symbol of unjust imperial rule, the easy availability of coffee helped it to become a replacement drink.

#### *Modern trends*

The recent history of coffee has been marked by a shift in marketing which has resulted in specialty shops which primarily sell coffee (as opposed to restaurants which focused primarily on food delivery, but offered coffee) and in dramatic increases in serving sizes. Starbucks, the leading coffee retailer in America, has over 8000 coffee shops in the USA alone and operates outlets in 36 countries (40,41). While the traditional size for a ‘mug’ of coffee has been 8 ounces, Starbucks markets 12-, 16- and 20-ounce sizes. In addition, Starbucks coffee contains a greater dose of caffeine per ounce than coffee did historically. A 20-ounce Starbucks coffee contains 500 mg of caffeine, twice the amount found in 20 ounces of non-gourmet coffee, and about equivalent to five shots of espresso (42).

The strong market for coffee beverages in the USA has encouraged many corporations to present convenient, premium roast options. Starbucks has introduced several pre-packaged drinks which are now available at venues ranging from gas stations to supermarkets, and other com-

panies have products planned for that same market (43,44). Those sweetened coffees, along with sugary coffee drinks offered at coffee chains, may be helping to encourage young people to drink coffee by creating a child-friendly version of a beverage that has traditionally been too bitter for most juvenile palettes. Other companies, such as McDonalds, Dunkin Donuts, Chick-fil-a and even Exxon-Mobil, are attempting to compete in the high-end coffee market by improving the quality of their roasts (43,45).

## Fruit and vegetable juices

### *History*

In the context of this research, juice is defined as the liquid part that can be extracted from plants. Our research has not found a thorough history of juice making. One problem with this research avenue is determining when ‘juice’ originated. Early agricultural communities may have squeezed fruit specifically for its juice. Accumulations of grape pips have been found which date from 8000 BCE, but those are generally considered evidence of wine production, rather than juice (29).

While the early history of juice is hard to investigate, the first modern ‘juice’ may have been lemonade, which appeared during the 16th century in Italy. Some scholars have suggested that lemonade (like so many of the beverages we drink) was actually invented in the Middle East and imported to Italy (46). By the mid-17th century, orange juice had joined the list of beverage choices (46). Early ‘sherberts’ also appeared in the mid-17th century. These were cooling fruit drinks introduced from Turkey (46). In the first half of the 18th century, Dr James Lind identified the ability of citrus fruits to prevent scurvy, and more than 100 years later the Merchant Shipping Act of 1867 made carrying citrus juices on ocean voyages a legal requirement for British vessels (46).

### *Modern trends*

Important innovations in the fruit juice industry in the last 100 years have included the use of pasteurization and the introduction of juice concentrates. Pasteurization is not applied as uniformly to juice as it is to milk. One major US fruit juice manufacturer, Welch’s, claims to have begun pasteurizing its grape juice in 1869, just a few years after the process was invented and decades before it was regularly applied to milk (47). In contrast, Odwalla only began pasteurizing after a 1996 outbreak of *E. coli* linked to its juice killed a child (48).

Juice concentrates were invented during World War II to help provide juice to combat troops. However, production facilities were not completed until 1945, so the domestic US market became the target. The intention was originally to produce powdered orange juice, but reconstituting the



powder did not work well. Instead, the Florida Foods Corporation (later to become Minute Maid) marketed an intermediate step in the powdering process as juice concentrate (49).

Juice companies are expanding on the historic healthy profile of their beverages by adding ingredients perceived to add further health benefits. Perhaps the most common is calcium- and Vitamin D-fortified orange juice, which accounted for 30% of Minute Maid juice sales in 2002 (50). However, vitamins and minerals are not the only additives being used. Spirulina, a blue-green algae, and herbs such as echinacea are also being mixed into juices (51).

### Soft drinks

The addition of soft drinks (calorically sweetened beverages with no nutritional benefits other than water and a source of energy) to the beverage pantheon began (rather ironically) with the intention of making healthier water. Throughout the history of human civilization, waterborne pathogens had been a source of disease. As a result, water was viewed with some suspicion and superstition (52). Most agreed that good water was running water found on a mountain, and the finest of all waters were those that came from European spas (32). The early soft drink-makers set out to use the emergent tools of laboratory science to reproduce those famous, naturally carbonated waters.

Carbonation techniques utilizing chalk and acid were developed in the 1760s (46,53). The resulting beverage was sometimes called soda water because early methods relied on bicarbonate of soda to create carbonation. Other substances such as pulverized marble were also used (53,54).

Soft drinks were first sold by Thomas Henry, a British pharmacist, who also published a pamphlet which helped disseminate the production techniques (54). The business of selling soda water soon involved names still associated with soft drinks today, such as that of Jacob Scheweppe. He began selling seltzer in Geneva in 1789, and later moved to London (53). In the USA, Benjamin Silliman of New Haven, CT is said to have been the first to produce carbonated water on a large scale, *c.* 1800 (53).

No one knows exactly when or by whom flavourings (and sweeteners) began to be added to seltzer (53). Mixtures of wine and carbonated water became popular in the late 18th and early 19th centuries (53). Effervescent lemonade was being sold by 1833 (46). By the 1830s, flavour syrups made from berries and fruit had been developed (53). In 1861, ginger ale was invented (53). That same year, the term 'pop' came to mean flavoured soft drink water in bottles (53). Flavours continued to diversify and by 1865, one supplier was advertising pineapple, black cherry, orange, apple, strawberry, raspberry, gooseberry, pear, melon, lemon, cherry, plum, grape, apricot and peach (53).

The invention of the ice cream soda is attributed to Robert Green in 1874. However, by that time it was already common for American pharmacists to add sweet cream to the seltzer they sold in their drug stores (46,53). Sarsaparilla and root beer were both added to the flavour repertoire before the turn of the century (46).

The soft drink industry expanded rapidly. In 1860 there were 123 plants bottling soft drink water in the USA (53). By 1870 there were 387, and by 1900 there were 2763 (53). The temperance movement in the USA and the UK contributed to the continued rise of the soda fountain, making pharmacies an alternative to bars (46).

Among the most important events in the history of soft drinks occurred in 1886 when J.S. Pemberton combined kola, the caffeinated nut from Africa (and a popular drink flavour in the UK) with coca, a stimulant from South America (and the parent plant of cocaine) to create Coca-Cola. He marketed it in the same way as many carbonated beverages, as a 'tonic' (in this case for the brain) (46). Dr Pepper had been in existence since 1885; Pepsi would follow in 1896 (53). In 1890, Coca-Cola sold 9000 gallons of its flavour syrup (53). In 1892, the Coca-Cola Company incorporated and authorized \$100 000 in capital stock, and by 1904 one million gallons of Coca-Cola syrup were being sold annually (53).

### Biological response to different beverages

Several studies show that intake of calorically sweetened beverages do not reduce the intake of solid food a corresponding amount (1,2,55–64). This issue has been reviewed recently by Mattes who separates beverages into different categories with respect to their effect on calorie compensation (3). In 1990 Tordoff *et al.* reported that drinking aspartame sweetened beverages for 3 weeks produced a small weight loss in comparison with a small weight gain when the same subjects drank calorie sweetened beverages (63). This concept was extended in 1994 when Mattes provided subjects with carbonated water, cola, or one of three varieties of beer with lunch. Energy intake was compared with the previous day. For all beverages except carbonated water, energy intake was significantly higher on the day the beverage was consumed than on the previous day (1). In 2000, DiMeglio and Mattes assigned subjects to two groups: one was required to consume 450 kcal d<sup>-1</sup> as a soft drink, and the other to consume the same energy as jelly beans. The participants could eat any other food they wanted but had to keep a record of consumption. The consumers of jelly beans reduced their caloric consumption by slightly more than the 450 kcal contained in the beans. The consumers of carbohydrate-containing soft drinks not only failed to reduce their caloric consumption to compensate for the soft drink, but also increased their consumption of other foods

slightly. Subjects consuming soft drinks showed a small but significant weight gain over the course of the study which did not occur with consumption of jelly beans (2). Taken together, these studies argue that sugar or HFCS calories in liquid beverages may not suppress intake of solid foods to help maintain energy balance. In a 2005 study, DellaValle *et al.* fed lunch to 44 women once a week for 6 weeks. At each meal, a different beverage was offered: water, diet cola, regular cola, orange juice, milk and no beverage. On the weeks when caloric beverages were consumed with the meals, average calorie consumption increased by  $104 \pm 16$  kcal over the level consumed when water, diet cola and no beverage were offered (62). The reduced compensation occurs in both men and women (64). The quantity of calorically sweetened beverages also increases as the portion size increases (64). Other studies not reviewed here also demonstrate a lack of compensation for calories consumed as beverages (56–61). See also the review by Mattes (3).

Randomized clinical trials are one of the most important ways of examining responses to experimental manipulations. Probably the most convincing randomized study of calorie-sweetened beverages was performed by Raben *et al.* They conducted a 10-week double-blind study with 41 overweight subjects given a fixed load of aspartame or sugar sweetened beverages (55). At the end of the study, the subjects drinking the sugar-sweetened beverages gained 1.6 kg and had a significant increase in blood pressure which contrasted with the weight loss of 1.0 kg in the subjects drinking aspartame beverages. Three markers of immune response (haptoglobin, transferrin and c-reactive protein) were also increased in the subjects drinking sugar-sweetened beverages, compared with a decline in the subjects drinking the aspartame-sweetened beverages (65).

The mechanism responsible for that weaker compensatory response to some fluids is unknown (5). One possible mechanism is the way in which the gastrointestinal track responds to the form in which it is exposed to those nutrients. Solutions can have stronger sensory responses than solid foods. Likewise, the components making up the beverages and solid foods, as well as the concentration of these components may play a role.

Figure 4 shows the characteristics of various beverages described above. The sight and smell of beverages are the first basis for response to the beverages and foods that we eat. If the sight or smell are 'repugnant', we may not eat, and we may also avoid food if there is 'danger' in the environment – the fight or flight response of Cannon (66). The next interaction is through the taste buds on the tongue. There are now five recognized tastes – sweet, sour, bitter, salty and umami – and a sixth one that has been identified in rodents and humans – the taste of fatty acids (67,68). There is also a response related to sickness and to allergy that can lead to 'aversion' to foods. For other foods,

the sight, smell and taste of food serve to initiate the vagal response – cephalic phase of digestion – that initiates insulin secretion and pancreatic secretion of enzymes that participate in the early phase of food digestion. In addition to initiating gastro-intestinal responses, the oral cavity has enzymes that can digest triglycerides (lingual lipase released from von Ebner's glands) and disaccharides.

In the stomach, several important events occur in response to food. First, the food is mixed and partially digested by peptidases and amylases to reach sizes suitable for entry into the small intestine. Second, the osmolality of the gastric contents are adjusted to close to the osmolality of other body fluids by secreting fluids into the stomach. Third, the gastric contents become acid, an environment in which the gastric enzymes can work. The mixture in the stomach then enters the intestine through the pylorus, a process that is controlled by caloric density and fat content of the foods. In studies in non-human primates, the rate of emptying was about  $1 \text{ cal min}^{-1}$  (69). Water, the preferred beverage in the Beverage Guidance System and the primary source of fluid for early human beings is rapidly emptied from the stomach, as it has no calories. Other beverages slow gastric emptying with foods containing fat slowing it the most (69).

As the gastric digest moves into the intestine, it is further digested by intestinal and pancreatic enzymes. Table 1 is a summary of some features of the gastric and intestinal peptides that are released in the presence or absence of nutrients. These peptides are released from endocrine cells in the gastro-intestinal track or nerve fibres and ganglia within the intestinal mucosa or from the endocrine cells in the islet of the pancreas, and have been subdivided in this table according to the storage and release site. What is directly relevant to this discussion is the relation of nutrients in the food to the pattern of gastrointestinal hormone secretion from the gastrointestinal (GI) track. Most of these peptides serve to reduce food intake, but two of them, ghrelin and pancreatic polypeptide can increase food intake. The peptides come largely from two large families: the secretin superfamily [vasoactive intestinal polypeptide (VIP); glucose-dependent insulinotropic polypeptide (GIP); glucagon; glucagon-like polypeptide-1 and -2; pituitary-adenyl cyclase-activating peptide; growth hormone releasing hormone; and oxyntomodulin], and the tachykinin superfamily (substance P; bombesin; substance K; neuromedin K & B; and gastrin releasing peptide). The fats and proteins in mixed meals enhance release of cholecystokinin (CCK) secretin, polypeptide YY, VIP and neurotensin. In contrast, carbohydrate is only involved in the release of glucagon-like peptide-1 and glucose insulinotrophic polypeptide (GIP) (Table 1). Protein, peptides and amino acids stimulate the release of CCK, pancreatic polypeptide, glucagon, gastrin. Fasting and gastric or intestinal distension can also influence the release of peptides with both ghrelin and motilin rising

**Table 1** Intestinal and pancreatic peptides that are affected by nutrients and that affect food intake

| Peptide  | Number of amino acids  | Produced                               | Effect of food intake                                     | Secretory stimuli   |
|--|--|--|---|---|
| Secreted from endocrine cells                              |  |  |   |   |
| Gastrin  | 34 AA and 17 AA  | G-cells                                |   | High pH and protein peptide and amino acids   |
| Glucose-dependent insulinotropic polypeptide (GIP)         | 42 AA  |  |   | Mixed meal; fat and glucose   |
| Ghrelin  | 28 AA with ocanoate on carbon-3                                  | Gastric oxyntic cells                  | Increases   | Fasting   |
| Glucagon-like-1 peptide                                    |  | Intestinal L-cells                     | Reduces   | Mixed meal; fat and glucose   |
| Mortilin   | 22 AA  | Intestinal M-cells                     |   | Released in fasting; Bombesin increases; insulin and corticotrophin releasing factor decrease |
| Peptide YY and PYY <sub>3-36</sub>                         |  | Intestinal L-cells                     | Reduces   | Fat   |
| Secretin   | 27 AA  | S-cells                                | Reduces   | Mixed meal; low pH; bile salts and fatty acids  |
| Secreted from nerve fibres and ganglia in intestinal cells |  |  |   |   |
| Cholecystokinin (CCK)                                      | 58; 33; 8 AA   | I-cells                                | Reduces   | Mixed meal; fat and protein   |
| Neurotensin  | 13 AA  | N-cells                                |   | Mixed meal with fat   |
| Somatostatin   | 14 AA and 28 AA  | D-cells                                |   | Mixed meal; low pH stimulated by GIP, secretin, CCK, gastrin                                  |
| Substance P  | 11 AA  | Myenteric plexus                       |   | Intestinal pressure   |
| Pancreatic peptides  |  |  |   |   |
| Vasoactive intestinal polypeptide                          |  |  |   |   |
| Amylin   | 37   | β-cells                                | Reduces   |   |
| Glucagon   | 29   | Intestinal L-cells<br>Pancreas A-cells | Reduces   |   |
| Insulin  | Proinsulin cleaved to insulin with two chains and 58 amino acids | β-cells                                | Increases peripherally; Reduces in central nervous system |   |
| Pancreatic polypeptide                                     |  | Pancreatic PP-cells                    | Increases   | Released by fatty acids, protein and glucose; Released by vagus                               |

with fasting. Thus, the pattern of peptide release from the GI track is dependent on the components of the meals, with a varied potential for the types of circulating and neural messages relayed to the brain.

These peptides are also satiety factors that reduce food intake. Carbohydrates, the major component of soft drinks, stimulate a smaller number of 'satiety factors' than fat or protein. They may also enter the intestine more rapidly than mixed meals. The failure to secrete important satiety factors that may occur after ingestion of soft drinks may contribute in a significant way to the failure to compensate when these beverages are ingested.

From this discussion, one might expect that the handling of beverages would be very different and that the ability to reduce intake of other foods would depend on the type of beverage. At one end is milk which contains fat, protein and carbohydrate. It would thus be expected to release all

of the GI satiety factors and to produce normal caloric compensation. This does seem to be the case. In contrast, beverages composed only of water and carbohydrates would be expected to be poorly compensated for by lowering intake of other foods to offset the caloric content of the beverages.

Alcohol, or ethanol, is an unusual molecule. The body does not make ethanol, and it cannot store ethanol as it can protein, carbohydrate and fat. Thus, ethanol must be oxidized. Its metabolism produces about 7 kcal g<sup>-1</sup> of energy and it serves as a 'fat equivalent'. The rate of ethanol oxidation is generally limited to the alcohol dehydrogenase pathway, except for those who have overconsumed ethanol and induced ethanol metabolizing enzymes in the peroxisomes.

Does consumption of alcoholic beverages reduce the intake of other nutrients or increase physical activity such

that weight is maintained, or does alcohol consumption add on calories with a resulting increase in body weight? Alcoholic calories account for 102 kcal d<sup>-1</sup> for the average US adult in 2002 and ranges as a percentage of daily energy intake for these adults from 3% to 9% (70,71), yet cross-sectional epidemiological studies show absent or weak positive relations of alcohol and body mass index (BMI) in men and negative relationship in women (72–74). One longitudinal study found that after 5 years of follow-up stable and ‘heavy’ drinkers had the greatest weight gain and had the highest prevalence of high BMI (75). This contrasts with the lesser weight gain over 10 years in the National Health Examination follow-up among both men and women drinkers as compared with non-drinkers.

Alcohol intake appears to be associated with little compensatory reduction in energy intake from other foods (76,77). When beverages containing glucose (dextrose) or ethanol were given at one of two levels volunteers compensated for about 37% of the extra energy whether it was glucose or alcohol. Thus, total energy intake in this acute study increased by 13–27% (76). The second study in healthy men gave them access to an alcohol beverage or placebo before a lunch that was either high in fat or low in fat. The combination of the alcoholic beverage with the high-fat meal increased energy intake by about 700 kcal.

Two explanations may be offered for the lack of weight gain and alcohol intake in the epidemiological studies when it would be predicted from the short-term metabolic studies showing failure of compensation. The first is that individuals who regularly consume modest amounts of alcohol may be more physically active. Westerterp *et al.* (78) found that individuals with higher alcohol intake had higher physical activity on days when they consumed alcohol as well as days when they did not. The second possibility is that subjects who are overweight underreport energy intake more than subjects who are not (79).

## Discussion

When human beings consume calories from carbohydrate-rich beverages, we do not reduce consumption of calories from solid food by the corresponding amount. The clearest rationale for that incomplete compensatory response is that we lack genetic information for a physiological response for responding to these beverage calories with complete satiation because we evolved with water as our major source of hydration. Beverages appeared in the human diet at the point in human evolution when selective pressure dramatically abated – just as the domestication of livestock and agricultural production reduced the risk of starvation. Although sugar-containing and alcoholic beverages contain energy (calories), these calories seem to be inadequately sensed by the satiety mechanisms in the GI track which control appetite and body fat. That may be because pro-

cessing these types of beverage calories was not codified by millennia of consumption in the way that food and milk calories were.

The issue of satiation following beverage consumption is particularly perplexing. Some would argue that beverages *do* produce satiation. Breast milk appears to satisfy the hunger of infants. Some researchers have found similar results when adults are asked to report their feelings of satiety after drinking a beverage (80). What is missing is caloric compensation in food consumption. Individuals consuming beverages shortly before or with a meal eat the same number of calories as individuals consuming a calorie-free beverage (1,2,56–62). Thus, it appears that some beverages do not trigger satiation in the same way that food does, and in fact may require a separate vocabulary for describing the feelings they create. One explanation may be the different patterns of peptides released from the gastrointestinal track when we drink any caloric sweetener (sucrose or HFCS normally) or alcoholic beverages as compared with milk or solid food. These patterns are a key part of the inhibition of food intake and sugar-containing and alcoholic beverages may produce inadequate inhibitory messages.

Beverage choices have expanded with ever increasing rapidity since humans first created settlements. In the last half century, new options have appeared extremely rapidly. Sports drinks, energy drinks and high-calorie alcoholic beverages such as hard lemonade – just to name a few – have all been added to long-standing options like milk, wine, beer, tea and coffee. Whether the history of beverages can help to guide us to healthier options and healthier choices remains an important question.

## Conflict of Interest Statement

No conflict of interest was declared.

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