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Orange Juice Limits Postprandial Fat Oxidation after Breakfast in Normal-Weight Adolescents and Adults[1–3]

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ABSTRACT

Caloric beverages may promote weight gain by simultaneously increasing total energy intake and limiting fat oxidation. During moderate intensity exercise, caloric beverage intake depresses fat oxidation by 25% or more. This randomized crossover study describes the impact of having a caloric beverage with a typical meal on fat oxidation under resting conditions. On 2 separate days, healthy normal-weight adolescents ($n = 7$) and adults ($n = 10$) consumed the same breakfast with either orange juice or drinking water and sat at rest for 3 h after breakfast. The meal paired with orange juice was 882 kJ (210 kcal) higher than the meal paired with drinking water. Both meals contained the same amount of fat (12 g). For both age groups, both meals resulted in a net positive energy balance 150 min after breakfast. Resting fat oxidation 150 min after breakfast was significantly lower after breakfast with orange juice, however. The results suggest that, independent of a state of energy excess, when individuals have a caloric beverage instead of drinking water with a meal, they are less likely to oxidize the amount of fat consumed in the meal before their next meal. *Adv. Nutr. 3: 629S–635S, 2012.*

Introduction

Caloric beverages are implicated in the development of obesity (1–3). At the population level, increases in caloric beverage consumption between 1976 and 2000 are associated with increases in obesity over the same period (4–6). At the individual level, caloric beverage intake is associated with weight gain (1,7–13). Interventions to decrease caloric beverage intake and increase drinking water are associated with reduced weight gain or weight loss (14–20).

Caloric beverages are thought to promote weight gain by increasing total energy intake (3). Many crossover experiments in children and adults report excess total energy intake when a meal is paired with a caloric beverage instead of drinking water. Caloric beverages result in excess total energy intake because individuals do not eat less food to compensate for the calories consumed in beverages (21–24).

This crossover study extends work linking caloric beverages with excess energy intake and weight gain by describing an associated effect on postprandial fat oxidation. The study illustrates how having a caloric beverage with a meal has a negative impact on both energy intake and fuel partitioning at the same time. Unlike drinking water, caloric beverages prioritize carbohydrate oxidation over fat oxidation by increasing carbohydrate availability and/or stimulating insulin secretion (25–28). During low- to moderate-intensity

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exercise, caloric beverages depress fat oxidation by 25% or more compared with drinking water (29–43). The aim of this study was to determine whether caloric beverage intake significantly depresses fat oxidation compared with drinking water under resting conditions, after a typical Western meal. The study compares the energy and fat balance of healthy normal-weight adolescents and adults 150 min after breakfast with orange juice versus drinking water. Assuming that a usual time interval between breakfast and the next meal or snack is ~3 h, the study considered whether healthy individuals who sit at rest after breakfast with orange juice instead of drinking water are likely to oxidize the amount of fat consumed at breakfast before their next meal.

Methods

Subjects

This randomized, crossover study involved healthy, normal-weight boys ($n = 3$), girls ($n = 4$), men ($n = 4$), and women ($n = 6$). The adolescents ranged in age from 11 to 17 y (mean ± SD: 14 ± 2 y) and had a BMI below the 85th percentile for age and sex (body weight: 57.1 ± 11.5 kg, height: 163.4 ± 9.5 cm). The adults ranged in age from 19 to 38 y (25 ± 7 y) and had a BMI between 18.5 and 24.9 (22.4 ± 1.3 kg/m^2).

Healthy normal-weight individuals were recruited for the study through flyers posted in hospital outpatient center waiting rooms and online classified (craigslist) advertisements. Respondents were screened for eligibility by telephone interview. Specific exclusion criteria included acute illness, weight loss within the past 2 mo, previous diagnosis of renal disease, congestive heart failure, adrenal insufficiency, syndrome of inappropriate secretion of antidiuretic hormone, chronic pain, psychogenic polydipsia, bleeding disorders, hemophilia, recent cancer chemotherapy, and use of weight loss, antidepressant, antipsychotic or lipid-lowering medications. Respondents who were underweight, overweight, or obese by self-report during the screening interview or by measured BMI (above the 85th percentile for age and sex) on arrival at the clinic were excluded from the study. Respondents with an allergy or aversion to the study foods or beverages were also excluded from the study. The protocol was approved by the Institutional Review Board of Children's Hospital and Research Center, Oakland, CA. To participate in the study, adults provided informed consent and adolescents provided assent and parental informed consent.

Experimental protocol

Each participant ate breakfast on 2 separate mornings at Children's Hospital Oakland, Pediatric Clinical Research Center. The mornings were spaced at least 2 d apart within a 3-wk period. The protocol was identical on both mornings, except for the type of beverage served with breakfast. In randomized order, participants were given either 500 mL of orange juice or 500 mL of drinking water with breakfast.

Before each clinic visit, the participants refrained from strenuous physical activity and alcohol for 24 h, and fasted overnight from 1100 (≥10 h). On arrival at the clinic, at ~0800, a fasting saliva sample was collected. The participant voided his or her bladder before fasting body weight was measured in duplicate using a calibrated clinical scale (Scale-Tronix, Carol Stream). Standing height was measured in duplicate using a standard wall-mounted stadiometer. Fasting, resting oxygen consumption (V_{O_2})[9] and carbon dioxide production (V_{CO_2}) were measured by indirect calorimetry before breakfast. Immediately before and after breakfast, participants rated their hunger and thirst using a visual analogue scale (44). Breakfast foods were served with the test beverage and were consumed within a 15-min interval. Postprandial, resting v_{O_2} and V_{CO_2} were measured by indirect calorimetry 30 and 150 min after the participants finished eating and drinking to capture the normal glycemic peak ~30 min after the meal and return to baseline within ~2 h after the meal. If individuals consume breakfast at 0900 and lunch at 1200, the 150-min time point would reflect status before lunch. To avoid discomfort and fear related to serial blood sampling via catheter (particularly for the adolescent participants), postprandial saliva samples were collected 30, 60, 90, and 120 min after breakfast to index the postprandial insulin response (45,46). A single postprandial blood sample was collected via venipuncture 180 min after breakfast. After the first void on arrival at the clinic, all urine was collected over the 3-h study period. Participants were allowed to void as needed and asked to void at 180 min after breakfast. Study participants were instructed to repeat the same 24-h pattern of diet and activity before their second clinic visit.

Meal composition

The study meal was intended to approximate a typical Western breakfast. The foods and orange juice were purchased at a local supermarket. All participants were given the same foods in the same amounts (**Table 1**), following the serving sizes indicated on the nutrition labels: 1 serving of cereal with 2% milk to cover the cereal and 1 serving of cream cheese on one half of a toasted plain bagel. All participants were given the same volume of test beverage, ~500 mL (or 2 cups), defined by the size of the bottle of the orange juice tested. The orange juice was served chilled, as it might be bought from the store or served at home, straight from the refrigerator. The drinking water was served from the tap at room temperature. Although the participants and clinic study staff were aware of the difference in breakfast drink, the laboratory staff were blind to the assigned beverage. Table 1 describes the energy, fat, and carbohydrate content of the study foods and beverages based on the nutrition label of each item.

Specimen collection and analyses

Unstimulated saliva samples were collected by instructing participants not to swallow for 2 min, to allow saliva to collect in the mouth, and then transfer the saliva through a straw into cryogenic tubes. The saliva was stored at −80°C until assayed for insulin by ELISA using a commercially available kit (IBL International Corp) and absorbance read on a microplate spectrophotometer (SpectraMax 340, Molecular Devices). Results were analyzed with a 3-spline software application provided by IBL International.

Urine was collected throughout the 3-h study period. Urine osmolality was determined on the first void by freezing point depression osmometer as an index of baseline hydration status. Urine collected after the first void was stored at −80°C until assayed for urinary nitrogen (N) by Hunter Laboratories.

Blood was collected once on each study day 180 min after the participants finished eating and drinking. Blood was collected in nonanticoagulated tubes and EDTA anticoagulated tubes. The samples were centrifuged to separate and aliquot serum and plasma, respectively. The samples were stored at −80°C until assayed. To index postprandial glucose and lipid clearance, serum was sent to Quest Diagnostics for determination of serum glucose and lipid profile by enzymatic methods (comprehensive metabolic test). Plasma insulin concentrations were measured by radioimmunoassay (Millipore). Plasma FFA and 3-hydroxybutyrate were measured as markers of fat tissue breakdown with enzymatic colormetric reagents (Wako Chemicals).

Table 1. Breakfast food and beverage composition[1]

	Amount served, *g*	Energy, *kJ*	Fat, *g*	Carbohydrate, *g*
Cereal	27	460	2	22
2% milk	122	272	3	7
Plain bagel	45	544	1	25
Whipped cream cheese	21	251	6	1
Tap water	473	0	0	0
Orange juice	473	879	0	51
Total for breakfast with water		1527	12	55
Total for breakfast With orange juice		2406	12	106

[1] Values represent the nutrient content of each breakfast item as reported on the food label.

[9] Abbreviations used: N, urinary nitrogen; NPREE, nonprotein resting energy expenditure; NPRER, nonprotein respiratory exchange ratio; V_{CO_2}, volume of CO_2 produced; V_{O_2}, volume of O_2 consumed.

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Indirect calorimetry

Indirect calorimetry was performed with the study participants lying down under a canopy mask (Quark RMR, COSMED) at 3 time points on each study day: before breakfast and 30 and 150 min after finishing breakfast. At each time point, gas exchange rates were recorded at 10-s intervals during a 5-min measurement period. The recorded measurement period began after participants had adjusted to the mask and rates had equilibrated. At each time point, the 10-s V_{O_2} and V_{CO_2} rates were averaged to estimate the 5-min mean rates.

Calculations and statistics

Stata SE software version 9.2 was used for all analyses (StataCorp). The nonprotein, resting energy expenditure (NPREE), respiratory exchange ratio (NPRER), and fat oxidation rate before, and 30 and 150 min after breakfast were estimated from the N and 5-min mean V_{O_2} and V_{CO_2} using the following formulas:

$$\text{NPREE (kJ/min)} = 4.2 \times (((4.686 + (1.096 \times (\text{NPRER} - 0.707))) \times (\text{Vo}_2 - (\text{N} \times 6.25 \times 0.966))) + 4.6 * \text{N} \times 6.25 \times 0.966)$$

$$\text{NPRER} = [\text{Vco}_2 - (\text{N} \times 6.25 \times 0.774)]/(\text{Vo}_2 - (\text{N} \times 6.25 \times 0.966)]$$

$$\text{Fat oxidation (g/min)} = 1.689 \times \text{Vo}_2 - 1.689 \times \text{Vco}_2 - 1.77 \times \text{N}$$

where O_2 and CO_2 were expressed in L/min, and N was expressed in g/min.

The trapezoidal method was used to calculate the AUC for NPREE and fat oxidation. With the NPREE curve expressed in kJ/min (y-axis) and time expressed in minutes (x-axis), the AUC NPREE estimates the energy expended while sitting at rest for 150 min after the test meal. Similarly, with the fat oxidation curve expressed in g/min (y-axis), the fat oxidation AUC is an estimate of the grams of fat oxidized in 150 min after the meal. The net difference of energy intake at breakfast minus energy expended in 150 min after each meal was calculated. Similarly, the net difference in fat consumed at breakfast minus fat oxidized in 150 min after each meal was calculated.

Mixed models that allow each person to serve as his or her own control were used to test for significant changes from fasting values in saliva insulin, NPREE, NPRER, and fat oxidation on a given study day and compare values at a given time point and AUC values between study days. Mixed models that compared study days controlled for the order of the breakfasts and the baseline value if different across study days.

Mixed models were also used to determine whether the breakfast beverage modified the slope of postprandial change in insulin and fat oxidation. These models included data from both study days, with dummy variables representing each time point, breakfast beverage type, and the interaction terms between time and beverage type. Dummy variables were used to allow for nonlinear change over time. Differences with a P value <0.05 in the mixed models were considered statistically significant.

Results

Seven adolescents and 10 adults completed the study. There were no significant differences in hunger or thirst ratings before or after breakfast across study days. There were no significant differences in hydration status before breakfast across study days, based on urine osmolality.

Table 2 describes saliva insulin before and after breakfast with orange juice and drinking water. For both age groups, fasting saliva insulin did not differ significantly across study days. After breakfast on both study days, saliva insulin increased significantly relative to baseline for both age groups. The postprandial increase in saliva insulin was prolonged when breakfast was paired with orange juice for both age groups. Saliva insulin was significantly higher than baseline at 60, 90, and 120 min after breakfast with orange juice. After breakfast with drinking water, saliva insulin was only elevated over baseline values up to 60 min in the adolescents and up to 90 min in the adults.

For the adolescents, the postprandial increase in saliva insulin was significantly steeper after breakfast with orange juice. Plasma insulin concentrations were significantly higher 180 min after breakfast with orange juice (**Table 3**). The magnitude of change in saliva insulin and the plasma insulin concentrations at 180 min did not vary significantly across study days for the adults.

Table 3 describes the blood lipids of the adolescents and adults 180 min after breakfast with orange juice or drinking water. For the adolescents, plasma FFA, plasma 3-hydroxybutyrate, serum cholesterol, triglycerides, VLDL, and LDL did not differ significantly across study days, but serum HDL was significantly lower after breakfast with orange juice. For the adults, plasma FFA and 3-hydroxybutyrate values were significantly lower and serum triglycerides and VLDL significantly higher after breakfast with orange juice.

Table 4 describes the NPREE before and after breakfast with orange juice and drinking water.

For the adolescents, a significantly lower fasting NPREE before breakfast with orange juice was followed by significantly greater postprandial increases in NPREE after breakfast with orange juice. As the NPREE did not change after breakfast with drinking water, the NPREE at 30 and 150 min after breakfast did not differ across study days.

For the adults, the fasting NPREE was significantly higher before breakfast with orange juice. On both study days, the NPREE was significantly increased relative to baseline 30 min after breakfast. The magnitude of change in NPREE did not vary significantly across study days.

The fasting NPRER was significantly lower before breakfast with orange juice for the adolescents. It did not differ significantly between study days for the adults. For both age groups, the NPRER increased significantly after breakfast with orange juice, and did not change from baseline after breakfast with drinking water.

For both age groups, the fat oxidation rate before breakfast did not differ between study days.

For both age groups, fat oxidation decreased significantly 30 min after breakfast with orange juice, but did not change significantly from baseline after breakfast with drinking water. The postprandial change in fat oxidation was significantly modified by breakfast beverage.

In the adolescents, breakfast with orange juice was associated with 0.04 ± 0.01 g/min (29%) less postprandial fat oxidation than breakfast with drinking water. In the adults, it was associated with 0.03 ± 0.01 g/min (31%) less postprandial fat oxidation.

Figure 1 describes the net intake of energy and fat from breakfast relative to the energy expended and fat oxidized over 150 min after breakfast. Although the net energy surplus at 150 min was significantly greater after breakfast with orange juice, there was a net energy excess on both study days. The energy expended over 150 min after breakfast, sitting at rest, was less than that consumed at breakfast

Table 2. Saliva insulin before and after breakfast with orange juice or drinking water[1]

	Saliva insulin, *pmol/L*				
	Baseline value, mean ± SE	Change relative to baseline			
		30 min, mean ± SE	60 min, mean ± SE	90 min, mean ± SE	120 min, mean ± SE
Adolescent					
Orange juice	65 ± 22	42 ± 23	97 ± 23[2]	78 ± 23[2]	46 ± 23[2]
Drinking water	62 ± 13	29 ± 13[2]	60 ± 13[2]	24 +/−13	15 +/−1.3
Adult					
Orange juice	53 ± 20	34 ± 19	90 ± 19[2]	63 ± 19[2]	48 ± 19[2]
Drinking water	54 ± 27	26 ± 25	83 ± 25[2]	55 ± 25[2]	42 ± 25

[1] Values are mean ± SEM, 7 adolescents and 10 adults.
[2] $P < 0.05$ compared with the corresponding baseline value.

on both study days. For both age groups, fat balance was significantly more positive 150 min after breakfast with orange juice. The adults had not yet oxidized the amount of fat consumed at breakfast in 150 min. After breakfast with drinking water, both age groups had oxidized more fat than they had consumed at breakfast.

Discussion

The purpose of this randomized crossover study was to explore whether caloric beverages might promote weight gain in healthy sedentary individuals, not simply by causing excess energy intake, but also by limiting resting fat oxidation. The study compared resting fat oxidation after 2 breakfasts of identical foods served with either orange juice or drinking water. The study describes how a common beverage choice can affect the metabolism of a commonly consumed meal, e.g., breakfast cereal plus toast.

By design, the total energy intake of the meal paired with orange juice was 882 kJ (210 kcal) higher than the meal paired with drinking water. The orange juice doubled the carbohydrate content of the meal. Both meals contained the same amount of fat (12g). Although both meals resulted in similar hunger and thirst ratings, and a net positive energy balance at the end of the 3-h study period, the fat oxidation rates were significantly lower after the breakfast with orange juice.

Over time, the differences in fat oxidation rates may be clinically important. In 150 min after breakfast with orange juice, the adolescents had just finished oxidizing the amount of fat consumed at breakfast. The adults had not yet oxidized the amount of fat consumed at breakfast. By contrast, during the same period after breakfast with drinking water, both age groups had already burned more fat than they had consumed at breakfast. The more positive fat balance after breakfast with orange juice may predispose to fat accumulation in sedentary individuals, if the interval between eating is 2–3 h, and fat is ingested at each meal.

Body fat accumulation occurs when fat intake and/or synthesis exceeds fat oxidation. Orange juice does not contribute to fat intake. Given its fructose content, orange juice may increase hepatic fat synthesis (11), although whole-body de novo fat synthesis from excess carbohydrate energy is reportedly negligible (47). In adults, surplus carbohydrate energy has been shown to increase body fat stores, not by conversion of the carbohydrate to fat, but rather by suppressing the oxidation of dietary fat (48).

In this study, although the fate of dietary fat was not followed isotopically, the significantly lower HDL cholesterol in the adolescents 3 h after the breakfast with orange juice suggested that orange juice delayed the clearance of dietary fat from chylomicrons. The insulin response to carbohydrate ingested with a meal can exacerbate the postprandial accumulation of intestinally derived chylomicrons in plasma (49).

Table 3. Blood glucose, insulin, and lipids of healthy normal-weight adolescents and adults 180 min after breakfast with orange juice or drinking water[1]

	Adolescent		Adult	
	Orange juice, mean ± SE	Drinking water, mean ± SE	Orange juice, mean ± SE	Drinking water, mean ± SE
Serum glucose, *mmol/L*	4.3 ± 0.2	4.5 ± 0.1	4.4 ± 0.2	4.6 ± 0.2
Plasma insulin, *pmol/L*	160 ± 28[2]	125 ± 35	132 ± 28	83 ± 14
Insulin/glucose, *pmol/mmol*	37 ± 6[2]	28 ± 7	30 ± 7[2]	19 ± 2
Plasma FFA, *mmol/L*	0.18 ± 0.02	0.38 ± 0.13	0.23 ± 0.05[2]	0.34 ± 0.04
Plasma 3-hydroxybutyrate, *μmol/L*	25 ± 1	71 ± 33	38 ± 6[2]	59 ± 9
Serum total cholesterol, *mmol/L*	3.8 ± 0.2	4.0 ± 0.5	4.3 ± 0.2	4.5 ± 0.2
Triglycerides, *mmol/L*	1.4 ± 0.2	1.3 ± 0.4	1.1 ± 0.1[2]	0.9 ± 0.2
VLDL, *mmol/L*	0.6 ± 0.1	0.6 ± 0.2	0.5 ± 0.1[2]	0.4 ± 0.1
LDL, *mmol/L*	2.0 ± 0.2	2.0 ± 0.3	2.3 ± 0.1	2.4 ± 0.1
HDL, *mmol/L*	1.2 ± 0.1[2]	1.3 ± 0.1	1.5 ± 0.1	1.6 ± 0.1

[1] Values are mean ± SEM, 7 adolescents and 10 adults.
[2] $P < 0.05$ compared with the corresponding value after breakfast with drinking water.

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Table 4. NPREE, NPRER, and fat oxidation rate before and after breakfast with orange juice or drinking water[1]

	Baseline value, mean ± SE	Change relative to baseline	
		30 min, mean ± SE	150 min, mean ± SE
NPREE, *kJ/min*			
Adolescent			
Orange juice	5.4 ± 0.4[2]	1.4 ± 0.2[3,4]	0.8 ± 0.2[3]
Drinking water	6.3 ± 0.5	0.4 ± 0.4	−0.1 ± 0.4
Adult			
Orange juice	6.0 ± 0.4[2]	1.7 ± 0.3[3]	0.5 ± 0.3[3]
Drinking water	5.3 ± 0.3	1.1 ± 0.2[3]	0.5 ± 0.2[3]
NPRER			
Adolescent			
Orange juice	0.72 ± 0.03[2]	0.17 ± 0.04[3,4]	0.06 ± 0.04
Drinking water	0.76 ± 0.03	0.04 ± 0.02	−0.04 ± 0.02
Adult			
Orange juice	0.80 ± 0.02	0.11 ± 0.02[3,4]	0.04 ± 0.02[3]
Drinking water	0.80 ± 0.03	0.01 ± 0.02	−0.01 ± 0.02
Fat oxidation, *g/min*			
Adolescent			
Orange juice	0.12 ± 0.01	−0.05 ± 0.02[3,4]	−0.01 ± 0.02
Drinking water	0.12 ± 0.02	−0.01 ± 0.01	0.02 ± 0.01
Adult			
Orange juice	0.10 ± 0.02	−0.04 ± 0.01[3,4]	−0.01 ± 0.01
Drinking water	0.09 ± 0.02	0.02 ± 0.01	0.02 ± 0.01

[1] Values are mean ± SEM, 7 adolescents and 10 adults. NPREE, nonprotein resting energy expenditure; NPRER, nonprotein respiratory exchange ratio.
[2] $P < 0.05$ compared with the fasting value before breakfast with drinking water.
[3] $P < 0.05$ compared with the corresponding baseline value.
[4] $P < 0.05$ compared with the change after breakfast with drinking water in a mixed model, controlling for order of the breakfasts and visit.

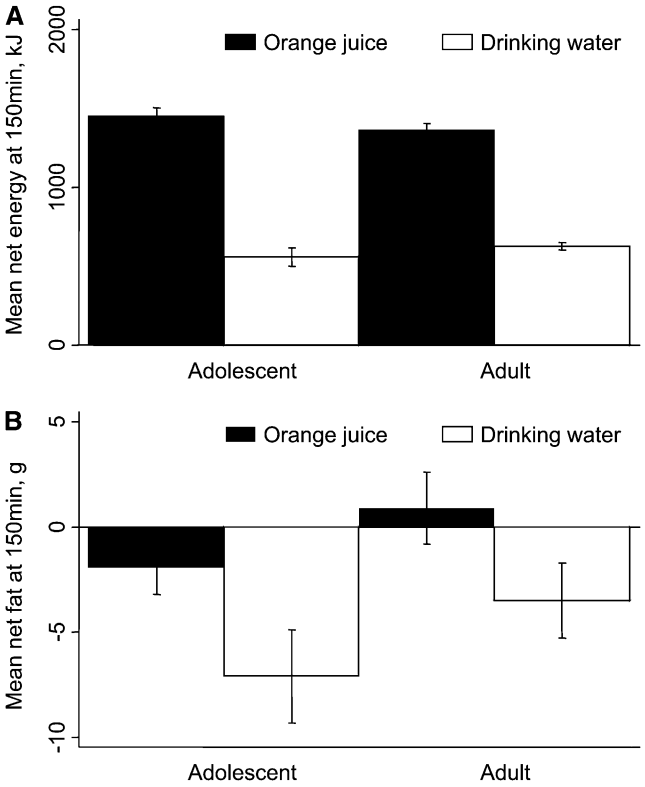

Figure 1. Net energy (*A*) and fat (*B*) intakes from breakfast minus expenditure over 150 min in adults and adolescents after consuming breakfast with orange juice and drinking water. Values were estimated using the nonprotein resting energy expenditure AUC (*A*) and fat oxidation AUC (*B*) and are mean ± SEM (7 adolescents or 10 adults). *Different from the corresponding after breakfast with drinking water, $P < 0.05$.

The significantly lower plasma FFA and 3-hydroxybutyrate after breakfast with orange juice in the adults is consistent with reduced breakdown and oxidation of body fat at the end of the postprandial period.

In the adolescents, breakfast with orange juice was associated with significantly higher postprandial insulin levels. Insulin is a very sensitive and key determinant of macronutrient metabolism. It inhibits the rate-limiting enzymes, hormone-sensitive lipase, acylcarnitine transferase, and pyruvate carboxylase that breakdown triglycerides to FFA, transport FFA into the mitochondria, and commit them to oxidation by the tricarboxylic acid/Krebs cycle (25). Even small increases in carbohydrate availability or insulin, such as those occurring after ingestion of fructose, are enough to depress fat oxidation (26).

In the adults, the saliva and plasma insulin concentrations did not differ significantly across study days. The significantly lower fat oxidation 30 min after breakfast with orange juice in the adults may therefore reflect noninsulin-mediated effects of fructose availability (50) or other factors such as gastric emptying, nutrient absorption, insulin sensitivity, glycogen stores, acid/base balance, cortisol, and hydration state. Fructose accounts for half of the carbohydrate in orange juice.

Significant differences in fat oxidation were observed in both age groups in this study, even though energy intake exceeded energy expenditure on both study days. The result suggests that reduced fat oxidation might mediate effects of caloric beverages on weight gain, independent of energy excess. In adults, reduced fat oxidation predicts weight gain, independent of metabolic rate (51).

This study was limited to a 3-h period of observation and 5-min snapshots of indirect calorimetry, as opposed to 24-h whole-body room indirect calorimetry. Thus, it can only raise questions about the long-term impact of frequent caloric beverage intake. If, after breakfast with juice, individuals then have lunch, snack, and dinner with a caloric beverage instead of water, will they have a positive fat balance at the end of the day? Reduced fat oxidation after 1 meal might be balanced out with greater fat oxidation later in the day if conditions are isocaloric (52). Caloric beverages, however, result in excess energy intake (i.e., a hypercaloric condition).

This study described the effect of having orange juice instead of drinking water with breakfast. Although the study only evaluated 1 kind of caloric beverage, other caloric beverages, including milks, other juices, sports drinks, and sodas, can also be expected to depress fat oxidation because these also contain carbohydrate and trigger insulin.

Effective interventions against obesity depend on understanding the biological mechanism.

If caloric beverages promote weight gain by suppressing fat oxidation under conditions of energy excess, then interventions

that maximize fat oxidation by limiting background carbohydrate and/or insulin levels, at the same time as reducing total energy intake, may be more effective against weight gain than interventions that target total energy intake only.

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