Carbohydrate Malabsorption May Increase Daily Energy Requirements in Infants

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OBJECTIVE: Carbohydrate malabsorption in infants has been found to increase nutrient losses. However, the effect of this alteration on daily metabolic rate is unknown. We assessed daily metabolic rates in infants with asymptomatic carbohydrate malabsorption (ACM) after a single fruit juice load.

METHODS: Sixteen healthy infants with ACM (63.3 ± 5.6 cm, 7.5 ± 1.0 kg, 5.6 ± 0.8 mo, peak breath hydrogen [BH_2] = 39.1 ± 22.4 ppm) and 16 without ACM (64.3 ± 3.9 cm, 7.8 ± 1.0 kg, 5.0 ± 0.8 mo, BH_2 = 9.4 ± 4.7 ppm), after a single fruit juice load, had 24-h energy expenditure (24-h EE; $kcal \cdot kg^{-1} \cdot d^{-1}$), resting (RMR; $kcal \cdot kg^{-1} \cdot d^{-1}$) and sleeping (SMR; $kcal \cdot kg^{-1} \cdot d^{-1}$) metabolic rates extrapolated from 3.5-h assessments in the Enhanced Metabolic Testing Activity Chamber. Furthermore, RMR was calculated with the World Health Organization (WHO), Schofield weight-based and weight- and height-based equations. Carbohydrate absorption was determined by BH_2. Differences ($P < 0.05$) were determined by *t* test.

RESULTS: All infants with ACM had greater ($P < 0.05$) extrapolated 24-h EE (91.2 ± 24.8 versus 78.0 ± 6.8) and RMR (71.8 ± 15.2 versus 59.5 ± 5.9). This represented an increase of 15–18.5%, respectively, in energy expenditures. Carbohydrate malabsorption was a significant determinant of EE, RMR, and SMR. However, the WHO (53.8 ± 1.0 versus 54.1 ± 0.9) and both Schofield equations (54.7 ± 0.9 versus 54.9 ± 1.0 and 50.6 ± 7.5 versus 47.3 ± 6.7) failed to detect any differences in RMR. There was a 20 percentile reduction in growth performance in infants with carbohydrate malabsorption.

CONCLUSIONS: Infants with ACM following fruit juice ingestion may have increased daily energy expenditure leading to increased metabolic requirements. *Nutrition* 2003;19:832–836. ©Elsevier Inc. 2003

KEY WORDS: Infants, resting metabolic rate, energy expenditure, physical activity, carbohydrate malabsorption

INTRODUCTION

Several investigators have demonstrated that fruit juices, such as apple or pear, that contain sorbitol and have high fructose-to-glucose ratios may cause carbohydrate malabsorption when fed to infants and children.[1–5] The malabsorption of carbohydrates produces excess hydrogen gas, which has been suggested as the cause of minor irritability or colic.[6,7,8] In one study in apparently healthy infants,[1] a serving of pear juice was associated with increased breath hydrogen gas (BH_2) excretion, metabolic rate, and physical activity over a 3-h period. Furthermore, similar results were obtained in another 3-h study in which infants were fed apple juice, a juice that has less than half the amount of sorbitol contained in pear juice.[9] These changes were determined by a new Enhanced Metabolic Testing Activity Chamber (EMTAC) that measures energy expenditure, resting and sleeping metabolic rates, and physical activity in infants up to 10 kg body weight.[1,9–11]

Many clinicians may be unknowingly calculating energy requirements in infants with asymptomatic carbohydrate malabsorption (ACM) when using many of the established formulas such as those by the World Health Organization (WHO) and Schofield.[12,13] However, these equations do not account for the presence of ACM. Further, they have been found to be inaccurate for calculating daily resting metabolic rates in healthy infants without any symptomatic or clinical manifestations carbohydrate malabsorption.[10]

It is not known whether there are changes in daily (24-h) metabolic rate associated with ACM in infants after consuming certain fruit juices with various amounts of sorbitol. The aim of this study was to determine whether extrapolated 24-h metabolic rate is increased, in relation to fruit juice intake, in infants with asymptomatic carbohydrate malabsorption.

MATERIALS AND METHODS

In this study metabolic data from 32 healthy infants were divided into two groups. One group consisted of 16 infants presenting with ACM (65.3 ± 6 cm, 7.5 ± 1.0 kg, 5.6 ± 0.8 mo, peak BH_2 = 39.1 ± 22.4 ppm after consuming 120 mL of fruit juice), and the other consisted of 16 infants without this condition (64.3 ± 3.9 cm, 7.8 ± 1.0 kg, 5.0 ± 0.8 mo, BH_2 = 9.4 ± 4.7 ppm after consuming

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TABLE I.

PHYSICAL CHARACTERISTICS, CARBOHYDRATE ABSORPTION STATUS, AND METABOLIC RATE IN EACH GROUP OF INFANTS BASED ON CARBOHYDRATE ABSORPTION STATUS*

Parameter	Carbohydrate absorption	Carbohydrate malabsorption	*P*
n	16	16	—
Age (mo)	5.0 ± 0.8	5.6 ± 0.8	<0.05
Length (cm)	64.3 ± 3.9	65.3 ± 5.6	NS
Body weight (kg)	7.8 ± 1.0	7.5 ± 1.0	NS
Fat-free mass (kg)	5.5 ± 0.7	5.5 ± 0.7	NS
Body fat (%)	29 ± 4	27 ± 5	NS
Weight/length (percentile)	66.9 ± 31.0	53.4 ± 33.5	NS
BH_2 (ppm)	9.4 ± 4.7	39.1 ± 22.4	<0.001
24-h EE ($kcal \cdot kg^{-1} \cdot d^{-1}$)	78.0 ± 6.8	91.2 ± 24.8	<0.05
RMR ($kcal \cdot kg^{-1} \cdot d^{-1}$)	59.5 ± 5.9	71.8 ± 15.2	<0.05
SMR ($kcal \cdot kg^{-1} \cdot d^{-1}$)	60.8 ± 4.8	68.8 ± 16.9	NS
WHO-RMR ($kcal \cdot kg^{-1} \cdot d^{-1}$)	54.1 ± 0.9	53.8 ± 1.0	NS
SHO-WT ($kcal \cdot kg^{-1} \cdot d^{-1}$)	54.9 ± 1.0	54.7 ± 0.9	NS
SHO-HTWT ($kcal \cdot kg^{-1} \cdot d^{-1}$)	47.3 ± 6.7	50.6 ± 7.5	NS

* Data are presented as mean ± standard deviation.
24-h EE, 24-h energy expenditure; BH_2, breath hydrogen gas levels; NS, non-significant; RMR, daily resting metabolic rate; SMR, sleeping metabolic rate; SHO-WT, Schofield weight-based equation for calculating resting metabolic rate; SHO-WTHT, Schofield weight- and height-based equation for calculating resting metabolic rate; WHO-RMR, World Health Organization equation for calculating resting metabolic rate

TABLE II.

CARBOHYDRATE CONTENT OF FRUIT JUICES FED TO INFANTS

Juice (g)	Fructose (g)	Glucose (g)	Fructose:glucose ratio	Sorbitol (g)	Sucrose (g)
White grape (g/dL)	7.5	7.1	1.1:1	0	0
Apple (g/dL)	6.2	2.7	2.3:1	.5	1.2
Pear (g/dL)	6.4	2.3	2.8:1	2.0	0.9

a similar amount of fruit juice). There were no significant differences in body size, composition, and growth performance among the two groups (Table I). All infants were involved in two prior studies of short-term metabolic changes associated with fruit juice consumption.[1,9] ACM was defined by the measurement of BH_2 excretion in apparently healthy infants over a 3-h period after the fruit juice load. The peak BH_2 value obtained that was equal to or greater than 20 ppm above baseline placed the respective infant in the ACM group. The fruit juices fed in both studies were apple, pear, or white grape (Welch Foods, Concord, MA, USA), given in a double-blind fashion. Further, there were no detectable differences with regard to appearance and odor between the three types of fruit juices. Apple and pear juices contain sorbitol and have high fructose-to-glucose ratios, whereas white grape juice is sorbitol free with a one-to-one ratio of fructose and glucose (Table II). All infants were growing normally between the 10th and 85th percentiles according to revised Centers of Disease Control criteria[14] and had no gastrointestinal symptoms before metabolic testing. They all had supine length (crown to heel) measured in duplicate with a horizontal stadiometer (Perspective Enterprises, Kalamazoo, MI, USA). Body weight was the average of two measurements obtained with an infant scale (Cardinal Detecto, Webb City, MO, USA). Skinfold thickness was the mean of two measures at each of five sites (biceps, triceps, sub scapular, flank, and quadriceps) on the right side of the body and was obtained with a Lange skinfold caliper (Beta Technology, Cambridge, MD, USA) according to a standard procedure.[15] Body fat and fat-free mass were calculated by appropriate equations.[16]

Informed written consent was obtained from at least one parent of each infant before metabolic measurements, and the study protocol was approved by the Institutional Review Boards of Miami Children's Hospital (Miami, FL, USA) and Maimonides Medical Center (Brooklyn, NY, USA). In these studies for which the data were derived, each infant was placed in the EMTAC for 3.5 h for continuous measurements of energy expenditure (EE; kcal/min) and an index of physical activity (PA; oscillations in weight per min/kg of body weight). This included a 30-min baseline period before fruit juice feeding. Metabolic testing started by 10:00 AM, and parental access to the infant was unrestricted. An observer recorded periods of observed infant sleep during the entire testing period. Before each metabolic measurement, the EMTAC was calibrated with standard gases containing known amounts of oxygen and carbon dioxide. All metabolic data from the EMTAC were corrected for parental interaction by eliminating any periods of EE and PA when parental interaction occurred. This represented approximately 15% of the energy expenditure data.[11] Thereafter, 24-h EE was extrapolated by multiplying mean EE across the entire testing period by 1440 min (number of minutes in 24 h). Resting metabolic rate (RMR) was calculated for each infant by regressing mean EE (kcal/min for 5 min) versus PA at each 5-min interval over the course of the study period. The *y* intercept of each regression equation was multiplied by 1440.[17]

RMR was also calculated by the WHO (males = [60.9 × body weight (kg)] − 54; females = [61.0 × body weight (kg)] − 51) and the Schofield weight-based (males = [59.48 × body weight (kg)] − 30.33; females = [58.29 × body weight (kg)] − 31.05) and weight- and height-based (males = [0.167 × body weight (kg)] + [1517.4 × length (m)] − 617.6; females = [16.25 × body weight (kg)] + [1023.2 × length (m)] − 413.5) equations.[12,13] Sleeping metabolic rate (SMR) was extrapolated by retaining all EE periods from the EMTAC where the infant was observed to be asleep and where the index of PA was less than or equal to 1.5. This mean was multiplied by 1440.[11,17] All extrapolated metabolic results (24-h EE, RMR, and SMR) were divided by the infant's body weight and expressed as kilocalories per kilogram per day. The respiratory quotient equalled the ratio of the corrected ventilation rate of carbon dioxide to oxygen (V_{CO_2}/V_{O_2}). The methodology of determining infant EE and PA and extrapolation of 24-h EE, RMR, and SMR have been validated.[1,9,17] While in the EMTAC carbohydrate absorption status was determined every 30 min after fruit juice consumption by BH_2 analysis, as previously described.[1,9]

Statistical differences in all anthropometric and metabolic parameters between the two groups of infants were determined by independent *t* test. The determinants of metabolic rate also were derived by regression analysis, with each metabolic component as the dependent variable and length, body weight, and carbohydrate absorption status (class variable with 0 = normal absorption, 1 = malabsorption) entered as independent variables. All data are presented as mean ± standard deviation.

RESULTS

Infants presenting with ACM had significantly ($P < 0.05$) greater BH_2 (Table I) and increased extrapolated 24-h EE and RMR than

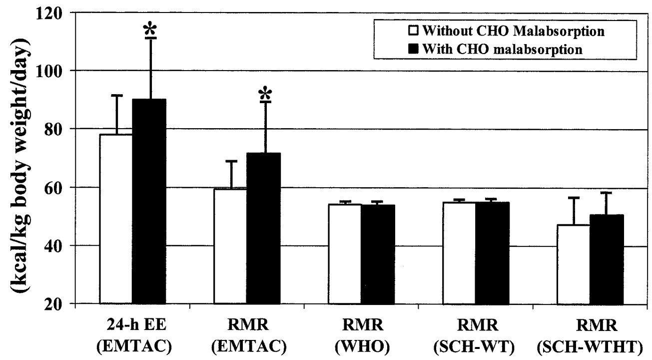

FIG. 1. The 24-h EE and RMR from the EMTAC and the RMR calculated by the WHO, SCH-WT, and SCH-WTHT in infants with and without asymptomatic CHO malabsorption. Data are shown as mean ± standard deviation. *Significant differences between groups. 24-h EE, 24-h energy expenditure; CHO, carbohydrate; EMTAC, Enhanced Metabolic Testing Activity Chamber; RMR, resting metabolic rate; SCH-WT, Schofield weight-based equation; SCH-WTHT, Schofield weight- and height-based equation; WHO, World Health Organization.

those without this condition (Fig. 1). These represented increases of 15.0% and 18.5%, respectively, in extrapolated 24-h EE and RMR. However, no correlation existed between BH_2 and 24-h EE, RMR, and SMR, respectively. But when carbohydrate absorption (CA) was entered into a regression analysis as an independent class variable (0 = normal absorption, 1 = malabsorption), it was a significant ($P < 0.05$) determinant of 24-h EE (171.1 + [0.9 × body weight] − [1.6 × length] + [14.2 × CA]), RMR (93.4 − [1.3 × body weight] − [0.4 × length] + [13.1 × CA]), and SMR (164.9 + [0.7 × body weight] − [1.7 × length] + [8.3 × CA]). Further, when infants were grouped according to whether they were fed sorbitol-containing or sorbitol-free fruit juices, those with ACM had greater extrapolated 24-h EE, RMR, and SMR than did similarly fed infants without this condition (Table III). A similar trend existed for infants fed fruit juices containing sorbitol such as apple and pear juices (Table III). All infants with ACM had peak BH_2 ranging from 21 to 111 ppm, whereas infants without this condition had peak BH_2 less than 20 ppm above baseline, regardless of the type of juice fed. When grouped by the type of juices fed (with or without sorbitol), infants with ACM fed either type of juice had greater peak BH_2 than did those with out this condition (Table III).

There was a 20th percentile reduction in growth performance in infants with ACM and consuming sorbitol-containing fruit juices when compared with those without this condition and consuming sorbitol-free fruit juices (Table III). However, using weight-for-length as the criterion, there were no significant differences in growth performance between infants when grouped according to CA status, though those fed the sorbitol-containing juice who had asymptomatic carbohydrate malabsorption were those who had the lowest weight/length (Table I).

In contrast to that determined by the EMTAC, the WHO and Schofield weight-based and weight- and height-based equations did not detect an increase in RMR in infants with ACM (Fig. 1). The EMTAC detected an increase ($P < 0.05$) of 11 kcal $\cdot$ kg^{-1} $\cdot$ d^{-1} in RMR in infants with ACM, whereas the WHO and Schofield equations detected only non-significant increases of less than 3 and 1 kcal $\cdot$ kg^{-1} $\cdot$ d^{-1}, respectively.

Among the infants with ACM, seven, four, one, and three of these infants were already being fed apple, a mixture, pear, and white grape juices, respectively, before the study. Moreover, one infant in this group was introduced to white grape juice for the first time on the day of the study. Of the infants without this condition, six, three, and five of them were being fed apple, a mixture, and white grape juices, respectively, before the study. Moreover, one infant each was introduced to apple and white grape juices, respectively, for the first time on the day of the study.

There were no significant differences between groups with regard to the amount of fruit juice consumed before the study. Daily fruit juice consumptions in infants with and without ACM, as reported by their parents, were 108 ± 66 mL (3.6 ± 2.2 oz) and 108 ± 48 mL (3.6 ± 1.6 oz) of juice per day, respectively.

TABLE III.

BREATH HYDROGEN GAS ANALYSIS, GROWTH PERFORMANCE, AND METABOLIC RATE FOR EACH SUBSET OF INFANTS WHEN GROUPED ACCORDING TO TYPE OF JUICE FED

Juice (composition)	*n*	Weight/length (percentile)	BH_2 (ppm)	24-h EE (kcal $\cdot$ kg^{-1} $\cdot$ d^{-1})	RMR (kcal $\cdot$ kg^{-1} $\cdot$ d^{-1})	SMR (kcal $\cdot$ kg^{-1} $\cdot$ d^{-1})
Normal carbohydrate absorption						
Without sorbitol	11	71.4 ± 28.5	9.1 ± 4.1	77.4 ± 6.8	59.8 ± 5.6	58.7 ± 3.7
With sorbitol	5	57.0 ± 37.5	10.2 ± 6.2	79.5 ± 7.3	58.9 ± 7.2	65.3 ± 4.0
Asymptomatic carbohydrate malabsorption						
Without sorbitol	5	59.4 ± 37.0	34.6 ± 5.4*	95.2 ± 21.0*	76.9 ± 14.1*	73.5 ± 16.5*
With sorbitol	11	50.9 ± 33.3	41.1 ± 27.7*	87.9 ± 27.0	70.0 ± 16.0	67.3 ± 17.6

* Significant at $P < 0.05$ as compared with normal carbohydrate absorption.

24-h EE, 24-h energy expenditure; BH_2, breath hydrogen gas expiration; RMR, resting metabolic rate; SMR, sleeping metabolic rate

DISCUSSION

The EMTAC demonstrated an increase in extrapolated 24-h EE and RMR in those infants with ACM. Moreover, there was a 20 percentile reduction in growth performance in infants with this condition that affected weight and length in a proportionate manner. The increase in daily metabolic rate may have been due to excess gas from malabsorbed carbohydrates causing discomfort, thus leading to greater EE. In this analysis most of the infants with ACM, according to peak BH_2 greater than 20 ppm above baseline, consumed apple or pear juice. However, a few of those fed white grape juice also presented this problem. Apple and pear juices contain sorbitol and have high ratios of fructose to glucose, whereas white grape juice does not contain sorbitol, therefore they are more likely to manifest carbohydrate malabsorption as demonstrated by others.[1–5,7,9]

This study used a new instrument, the EMTAC, to determine changes in metabolic rate. It allowed detection of metabolic differences in relation to asymptomatic carbohydrate malabsorption.[9] Further, this new instrument has been used for clinical studies in infants with medical conditions such as acquired immunodeficiency syndrome, hypothyroidism, intrauterine growth retardation, colic, and obesity.[1,9] To date, metabolic measurements have been conducted in 100 infants. All tolerated the procedure well, and the results have led to changes in nutrition support[1] and current recommendations for juice consumptions in infants.[9] Additional research is needed to determine the changes in metabolic rate associated with the consumption of other foods that may cause carbohydrate malabsorption, i.e., lactose.

Because infants consume small amounts of fruit juice throughout the day, our extrapolated results for those infants with ACM may represent true-to-life energy needs. Two previous studies[1,9] only concentrated on changes in metabolic rate over 3 h. However, no one has attempted to determine changes over 24 h. Recently, extrapolation of short-duration metabolic measurements[18] was validated based on continuous metabolic measurements in infants for 24 h. This report allowed us to reanalyze our data from the two previous studies presented, without the need to conduct actual 24-h metabolic tests, to determine whether there was a possibility of increased 24-h metabolic rate with carbohydrate malabsorption. Moreover, our results were based on one fruit juice load. It is possible that increases in metabolic rate of greater magnitudes might have been present if infants with ACM had been consuming fruit juices throughout the day. Moreover, this was confirmed by regression analysis in which ACM was a factor determining daily energy needs in our infants. Therefore, based on our results, short-duration metabolic measurements in infants presenting with ACM after a one-time fruit juice load are indicative of 24-h metabolic rate. Moreover, problems with adequate growth may result if this condition is left undetected for an extended period. This has extreme importance for clinicians who need to determine the daily energy needs of infants with various asymptomatic metabolic disorders early on, thus possibly preventing problems with long-term poor growth.

It is possible that some of the infants fed apple or pear juice in the non-carbohydrate malabsorption group were introduced to fruit juices at younger ages, thus allowing for adaptation. This may explain the lack of carbohydrate malabsorption at the time of metabolic measurements.[9] However, the opposite may have been true for infants in the carbohydrate malabsorption group fed white grape juice. They may have just been introduced to fruit juices a short time before the study. Therefore, they may have been sensitive to any type of carbohydrates from fruit juices, thus explaining why they exhibited carbohydrate malabsorption at the time of metabolic measurements.

Other associated conditions, such as infantile colic, may exacerbate carbohydrate malabsorption. In a recent study, infants with colic and fed apple juice showed greater increases in PA and metabolic rate over a 3-h period than did those without colic fed the same juice. Further, these infants showed increased crying and decreased sleeping times.[9]

Carbohydrate malabsorption caused by fruit juice consumption may lead to other clinical manifestations. For example, children fed pear or apple juice during treatment of acute diarrhea suffered carbohydrate malabsorption and recurrence of diarrhea during the recovery phase of treatment. However, feeding white grape juice during this period had no effects.[19] Further, feeding apple or pear juices to young children with chronic non-specific diarrhea caused carbohydrate malabsorption and increased the incidence of the disorder.[20]

Poor infant growth may be the result of asymptomatic clinical conditions causing problematic interactions between mother and infant. For example, one study found that infants with failure-to-thrive syndrome exhibited considerably more negative behaviors. These negative behaviors likely resulted from underlying physiologic response patterns, specifically activity of the autonomic nervous system.[21] In another study, infants with cow's milk allergy showed poor growth performance before treatment with an elimination diet.[22] Unnoticed behavioral changes related to discomfort from carbohydrate malabsorption in infants might lead to reduced nutrient intake, thus resulting in reduced growth performance, such as the almost 20th percentile reduction found in those infants with ACM and consuming sorbital-containing fruit juices. Further, the EMTAC was able to detect the minor increases in metabolic rate due to an asymptomatic condition, such as carbohydrate malabsorption. Early detection of such changes in metabolic rate and PA may allow health care professionals to intervene, change the infant's food and beverage intakes, and possibly avoid poor growth performance over a long period.

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