Substrate utilization in boys during exercise
with \(^{13}\)C-glucose ingestion

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Abstract The influence of glucose ingestion on substrate utilization during prolonged exercise in children and adolescents is currently unknown. In the present study we determined the effect of intermittent exogenous glucose (GLU\text{exo}) ingestion on substrate utilization during prolonged exercise, in adolescent boys ages 13–17 years. Healthy untrained volunteers performed four 30-min exercise bouts on a cycle ergometer, separated by 5-min rest periods (\(\approx 60\%\) maximum \(\dot{O}_2\) consumption), on two occasions spaced 1–4 weeks apart. Two trials were performed, a control trial (CT), in which subjects ingested water intermittently during the exercise, and a glucose trial (GT), in which subjects ingested a \(^{13}\)C-enriched GLU\text{exo} drink (\(\approx 3\) g glucose \(\cdot\) kg body mass\(^{-1}\)), also intermittently during the exercise. Total free fatty acids (FAT\text{total}), glucose (GLU\text{total}) and carbohydrate (CHO\text{total}) oxidation was determined from indirect calorimetry, while GLU\text{exo} oxidation was calculated from the \(^{15}\)C/\(^{12}\)C ratio in expired air after 5–10 min and 25–30 min of exercise in each bout. Heart rate and rating of perceived exertion (RPE) were determined at the same time intervals. The oxidation of CHO\text{total} was 169.1 (12.9) g \cdot 120 \text{ min}^{-1} and 203.1 (15.9) g \cdot 120 \text{ min}^{-1} (\(P < 0.01\)) and that of FAT\text{total} was 31.0 (4.2) g \cdot 120 \text{ min}^{-1} and 17.1 (2.5) g \cdot 120 \text{ min}^{-1} (\(P < 0.01\)) in CT and GT, respectively. GLU\text{exo} oxidation in GT was 57.8 (4.3) g \cdot 120 \text{ min}^{-1}, or 34.2 (2.2)\% of that ingested. Endogenous glucose oxidation was 169.1 (12.9) g \cdot 120 \text{ min}^{-1} and 145.3 (11.9) g \cdot 120 \text{ min}^{-1} (\(P < 0.01\)) in CT and GT, respectively. Insulin and glucose concentrations were higher in GT than in CT by 226\% and 37\%, respectively (both \(P < 0.05\)). Free fatty acids and glycerol concentrations were lower in GT than in CT, by 27\% and 79\%, respectively (both \(P < 0.05\)). Heart rate was similar between trials, but RPE was lower in GT vs CT at both 115 and 135 min. Thus, under these experimental conditions, GLU\text{exo} intake spares endogenous carbohydrate and fat by 16\% and 45\%, respectively, contributes to approximately 25\% of the total energy demand of exercise, and lowers the RPE.

Key words Children \cdot Carbohydrate oxidation \cdot Stable isotopes \cdot Physical activity \cdot Blood glucose

Introduction

In adults, a high carbohydrate (CHO) diet has long been known to increase muscle and liver glycogen concentrations prior to exercise and to increase exercise tolerance (Christensen and Hansen 1939; Bergstrom et al. 1967). Exercise performance may also be improved by ingesting CHO immediately before and/or during the exercise period (Coggan and Coyle 1991). CHO intake immediately before and/or during exercise is thought to postpone fatigue by maintaining high rates of glucose oxidation and blood glucose concentrations (Coyle et al. 1986; Coggan and Coyle 1987), and possibly by sparing muscle glycogen levels late in exercise (Hargreaves et al. 1984; Bosch et al. 1996). Indeed, at least in adults, the main source of substrate utilized when muscle glycogen levels are reduced by prolonged exercise (120 min) appears to be exogenous glucose (GLU\text{exo}; McConell et al. 1994).

Fewer data are available on substrate utilization during prolonged exercise in children and adolescents. During relatively short-term, moderate-intensity exercise performed without CHO ingestion, children and
adolescents seem to oxidize more fat and less glucose total carbohydrate (CHO<sub>total</sub>) compared with adults (Macek et al. 1976; Asano and Hirakoba 1984; Rowland et al. 1987; Martinez and Haymes 1992). The influence of CHO intake either before or during exercise in children and adolescents is currently unclear. Previously, Hendelman et al. (1997) showed that a pre-exercise CHO feeding snack does not alter the respiratory exchange ratio (R), prolong fatigue, or increase cycling time to exhaustion during 75 min of exercise in healthy adolescents. On the other hand, using 13C-labeled glucose, we have shown that the intermittent ingestion of 6–8% glucose during 60 min of moderate-intensity exercise contributes to ≥10% of the total energy provision in adolescent boys both with and without Type 1 diabetes mellitus (Riddell et al. 2000). The influence of exogenous glucose (GLU<sub>exo</sub>) on substrate utilization in adolescents during more prolonged exercise (i.e. > 60 min), when endogenous fuels may be limiting and GLU<sub>exo</sub> oxidation rates may be considerably higher, is currently unknown.

Stable, isotopic tracer methods (e.g., 13C-glucose) have been developed and revised that may be used to measure non-invasively the oxidation rate of orally ingested substrates. We have used these techniques previously to show that GLU<sub>exo</sub> utilization during 1 h of exercise is lower in adolescents with insulin-dependent diabetes mellitus (IDDM) compared with age- and weight-matched healthy adolescents. No studies exist, however, in which the influence of GLU<sub>exo</sub> during prolonged (120 min) exercise in healthy children or adolescents has been examined.

The purpose of the present study, therefore, was to determine substrate utilization, including GLU<sub>exo</sub> oxidation rates, during prolonged, 2 h moderate-intensity intermittent exercise performed with water ingestion and with 13C-enriched GLU<sub>exo</sub> ingestion in healthy, but untrained, adolescent boys. We hypothesized that compared with water intake, GLU<sub>exo</sub> intake would contribute significantly to the energy demand provision, spare endogenous CHO (CHO<sub>endo</sub>) and fat, and maintain blood glucose concentrations, of exercise, especially during the later stages of prolonged exercise.

### Methods

**Subjects**

Eight 13- to 17-year-old boys volunteered to participate in this study in response to local public service announcements. All were healthy, non-obese, habitually active, but not competitive athletes. The purpose, nature and possible risks of the experiment were explained to the boys and their parents. Subjects 14 years or older signed informed consent forms, while those under 14 years of age gave verbal assent. For all subjects, a parent or guardian subsequently signed an informed consent. The study was approved by the Research Ethics Board of the Faculty of Health Sciences, McMaster University. The mean (SD) age, height, body mass, percent body fat and maximal O<sub>2</sub> uptake (V<sub>Omax</sub>) of the subjects were 15.0 (1.2) years, 170.2 (8.5) cm, 60.4 (6.5) kg, 15.4 (4.9)%, and 45.7 (5.3) ml·kg<sup>-1</sup>·min<sup>-1</sup>, respectively.

**Pre-testing**

Height, body mass, percent body fat (1990B Bio-resistance Body Composition Analyzer, Valhalla Scientific) and V<sub>Omax</sub> was considered to have been reached if at least two of the following criteria were met: heart rate (f<sub>H</sub>) within 10 beats of the age-predicted maximum, R > 1.0, leveling off of O<sub>2</sub> uptake V<sub>O2</sub> with increasing exercise intensity, or volitional exhaustion (subject unable to maintain a pedal cadence above 60 rpm, in spite of encouragement by the investigator).

**Experimental trials**

Each subject attended two experimental trials spaced 1–4 weeks apart. The trials were identical except for post-breakfast fluid/carbohydrate intake. Each consisted of four 30-min bouts of cycling at 60% V<sub>O2</sub>max on a cycle ergometer. The bouts were separated by 5-min rest periods. During the first, control trial (CT), subjects ingested water intermittently during the exercise to allow the determination of baseline values of substrate oxidation. During the second, glucose trial (GT), they ingested intermittently a 13C-enriched GLU<sub>exo</sub> solution that was equal in the amount of glucose to the CHO<sub>total</sub> oxidation measured in the CT. This GLU<sub>exo</sub> feeding pattern was chosen since it helps to scale for the wide ranges in the CHO<sub>total</sub> oxidation observed in our subjects, and because it provides a large quantity of exogenous substrate available for oxidation (approximately 1.4 g·kg<sup>-1</sup>·h<sup>-1</sup> exercise in this study).

**Protocol**

Subjects were asked to avoid excessive physical activity on the day prior to the experimental sessions and to eat their usual meals, but come fasted on the morning of the trials. Figure 1 shows a timeline of the visit. After arrival to the laboratory at 8 a.m., subjects were provided with an individualized breakfast that matched their usual CHO [80 (20) g], protein [20 (6) g] and fat [11 (11) g] intake based on their reported 3-day dietary intake. The ingestion of CHO naturally enriched in 13C-CHO was avoided to help maintain a low background 13C enrichment in expired CO<sub>2</sub> (Peronnet et al. 1990). The start of the first bout of exercise (time = 0) on an electronically braked cycle ergometer (Corval 400, Lode, The Netherlands) began 100 min following the start of breakfast. The four bouts were separated by 5-min rest periods to reduce boredom and to allow the subjects to empty their bladder. The exercise was terminated if the subject was unable to maintain a cycling cadence of 60 rpm. Beverages were provided 20 min and 5 min prior to the start of the first exercise bout and at regular intervals during exercise (Fig. 1). During the CT, subjects were given plain water to maintain euhydration (approximately 200 ml at each drink period). In the GT,

**Fig. 1** Trial protocol. The exercise task (hatched bars) comprised four 30-min bouts (60% maximum oxygen consumption, V<sub>O2</sub>max) separated by 5-min rest periods. Drinks consisted of water (control trial, CT) or glucose (glucose trial, GT). (RPE: Rating of perceived exertion, f<sub>H</sub> heart rate, Gas sampling of oxygen consumption, CO<sub>2</sub> output and 13C/12C in expired CO<sub>2</sub>, Blood sampling for whole blood glucose, lactate and glycerol concentrations and plasma free fatty acid and insulin concentrations)