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Glycemic and Lactate Responses of Oral Hydration Solutions in Healthy Adults at Rest and Moderate Exercise

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ABSTRACT

Kuecher, AM, Smaldino, RJ, OHara RB, Linderman JK. Glycemic and Lactate Responses of Oral Hydration Solutions in Healthy Adults at Rest and Moderate Exercise. **JEPonline** 2017;20(3):66-78. The purpose of this investigation was to summarize and contrast the availability of glucose following consumption of a glucose solution, a commercial electrolyte drink (Gatorade), and a rice-based sports drink (CeraSport) at rest and during moderate exercise. This research focuses on changes in glucose, lactate, and fluid balance. Following a 12-hr overnight fast, male (n=10) and female subjects (n=10) underwent an oral glucose tolerance test (OGTT) at rest or during 60 min of moderate intensity exercise following consumption of glucose (G; 200 kcals; 1250 mL), Gatorade (200 kcals; 882 mL), an isocaloric CeraSport solution (C-ISOC) or an isovolumetric solution of CeraSport (C-ISOV). Blood glucose was significantly elevated 35 min following ingestion of C-ISOC when compared to other treatments at rest and during exercise ($P<0.05$). A lower caloric content of CeraSport (C-ISOV) resulted in similar elevations in blood glucose as either G or Gatorade. Blood lactate was significantly increased within 15 min of carbohydrate ingestion at rest and during exercise, but no treatment effects were found. The higher glycemic responses of CeraSport at rest and during exercise suggest greater total carbohydrate absorption when compared to either glucose or sucrose based carbohydrate electrolyte drink. It is likely that additional routes of absorption, such as longer chain carbohydrate absorption in the ileum, resulted in a higher glycemic response.

Key Words: Glucose, Oral Glucose Tolerance Test, Sports Drink

INTRODUCTION

Hydration is important during prolonged physical activity in all environments, but particularly in hot and humid (hyperthermic) environments. Total body water stores provide sweat for heat loss through evaporation and convection, as well as to maintain circulatory function (45). Fluid loss of approximately 2% of total body mass has been shown to decrease physical performance and result in thermal injury of varying severity from heat cramps to heat stroke (6,11,27,33,45). Hydration at a rate of 250 mL every 15 min is recommended by the American College of Sports Medicine, and a cool carbohydrate electrolyte solution of no more than 6% carbohydrate has been shown to result in maximal absorption when compared to water (2,9,18,26,36).

CeraSport® contains a carbohydrate mixture different than other commercial carbohydrate-electrolyte drinks that typically use sucrose or table sugar as an energy source. CeraSport® is made from brown rice syrup, which contains primarily maltose (>65%), but also other more complex molecules such as maltotriose and dextrins (8). The carbohydrate in CeraSport® provides the same quantity of energy as other commercial carbohydrate-electrolyte drinks, but yields a lower overall osmolarity (particle concentration) that may allow for improved absorption of water from the gut into the blood stream. Previous research using oral rehydration solutions containing brown rice syrup have demonstrated an improvement in the symptoms of cholera, such as severe diarrhea, when compared to water or other solutions (4,13,14,17,20,24,28,31,46). In addition, a recent report suggests that CeraSport® provided greater hydration when compared to water during heavy exertion in the United States Armed Forces training in hyperthermic conditions, as determined by changes in body weight (1,12).

It is understood that the availability of an energy source is related to its concentration in the blood (2,44). Also, it is known that carbohydrate supplementation enhances performance and delays fatigue during prolonged exercise (2,3,37,41). The glycemic response of carbohydrate type, such as solid and liquid, as well as composition, such as monosaccharides, disaccharides, and glucose polymers have been previously studied (43). However, the glycemic response of an oral rehydration solution or sports drink containing brown rice syrup when compared to sucrose or glucose is unknown (15,21). Recently, Moore and O'Hara suggested that the longer chain dextrins found in brown rice syrup are absorbed in the jejunum and ilium (25). It is possible that a carbohydrate solution containing glucose polymers including maltose, maltotriose, and dextrins may exploit multiple routes of absorption and increase substrate availability.

Ingested carbohydrates also differ in route of disposal that follows one of two distinct pathways of disposal to the liver, which is known as the direct or indirect pathways (16). The direct pathway transports glucose through the hepatic portal system to the liver where glucose uptake results in glycogenesis (16). As to the indirect pathway, glucose is first transported to the skeletal muscles to be converted to lactate through glycolysis (16). The lactate produced is then transported to the liver where it will be converted to glucose and glycogen as described by Cori (10). To date, little is known about the lactate response of ingested carbohydrates in sports drinks. However, recent research by Azevedo et al. indicates that sports drinks containing lactate increase high-intensity exercise performance in fit male cyclists. Collectively, the research indicates that carbohydrate sources other than sucrose provide superior fluid absorption at rest, and may more effectively mitigate physical performance decrements associated with prolonged physically demanding work.

It is well known that exercise alters glucose metabolism and, therefore, glycemic response (39). Exercise increases glucose oxidation, glucose uptake by skeletal muscle, and the conversion of glucose to lactate. Hence, in addition to understanding the glycemic responses of carbohydrates at rest, it is also important to understand how the activation of muscles may alter the glycemic responses and blood lactate concentrations of sports drinks differing in carbohydrate composition.

The purpose of this investigation was to contrast the glycemic response of a glucose solution, a rice-based sports drink (CeraSport), and a commercially available electrolyte drink containing sucrose at rest and during low to moderate intensity exercise in healthy adults in a fasted state. This research focused specifically on changes in blood glucose, blood lactate, and fluid balance.

METHODS

Subjects

A total of 40 healthy subjects (20 male, 20 female) were recruited at the University of Dayton with a mean age of 26.5 yrs ± 9.6 (males) and 24.3 yrs ± 5.6 (females). The inclusion criteria stated that each subject must be ≥19 yrs of age, free of musculoskeletal injuries within the past 3 months, free of CVD, and free of metabolic disorders such as diabetes. The study was approved by the University of Dayton Institutional Review Board and each subject signed an informed consent.

Sports Drink

Each subject completed 4 total trials per phase. Each trial entailed a different electrolyte beverage selected at random by the investigator (Table 1). The four solutions included glucose (G), CeraSport, and Gatorade. As presented in Table 1, the caloric content per unit volume of CeraSport differed from the commercially available Gatorade. As a result, two solutions of CeraSport were used that were either isocaloric to Gatorade (C-ISOC) or isovolumetric to Gatorade (C-ISOV). The glucose solution (50 gm for every 148 mL) was combined with Ultima Replenisher, a calorie free electrolyte powder to a volume of 1250 mL, which was isovolumetric to C-ISOC. The osmotic compositions of the carbohydrate, sodium, and potassium of the four solutions were calculated from product labels.

Table 1. Electrolyte Beverage Characteristics.

Beverage	Fluid (mL)	mOsm	CHO (gm)	Calories (kcals)	Na^+ (mg)	K^+ (mg)
Glucose	1250	239	50	200	138	625
Gatorade	882	202	50	200	400	113
CeraSport	1250	145	50	200	575	200
CeraSport	882	145	35.3	141	403	140

mL = milliliters; **mOsm** = milliosmolar; **gm** = grams; **kcals** = kilocalories; **mg** = milligrams; **CHO** = carbohydrate; **Na^+** = Sodium; **K^+** = Potassium

Procedures

Phase I - Rest

The subjects reported to the lab in the morning after completing a 12-hr fast. Baseline blood glucose and blood lactate were measured prior to a modified oral glucose tolerance test (OGTT) in which the subjects were given a sports drink chosen at random by the investigators (Table 1). Blood glucose and blood lactate were monitored 15 min post-beverage ingestion and every 20 min for a period of 80 min. Blood glucose was measured using a portable glucose analyzer (Accu-Chek Compact Plus Glucose Analyzer). Blood lactate was calculated by a portable lactate analyzer (NOVA Biomedical Lactate Plus Analyzer). At the completion of the OGTT, total urine volume was collected and recorded

Phase II - Exercise

The subjects reported to the lab in the morning after completing a 12-hr fast. Baseline body weight, blood glucose, and blood lactate were measured prior to the OGTT. Following the baseline measurements, the subjects were randomly assigned to one of the four carbohydrate-electrolyte beverages (Table 1). Then, the subjects participated in a low to moderate intensity treadmill protocol (3.5 $mi \cdot hr^{-1}$ at a 5% grade) for a total of 60 min. Blood glucose and blood lactate were monitored every 15 min for 60 min. Total body weight and urine volume measurements were taken at the conclusion of the 60 min.

Statistical Analyses

The data were analyzed using IBM SPSS Statistics 22. A 2-way, repeated measures ANOVA with a significance level of $P<0.05$ were used to compare the main effects of time and treatment, as well as time by treatment interactions for blood glucose and blood lactate. A probability of least squared difference (LSD) *post hoc* analysis values was used to compare means ($P<0.05$). Peak values of blood glucose, blood lactate, and total urine volume were compared using a 1-way ANOVA and least squared difference (LSD) *post hoc* analysis. Statistical significance was set at $P<0.05$ for all comparisons.

RESULTS

Subject Characteristics

The subjects' age and BMI by treatment are shown in Table 2.

Table 2. Subject Characteristics.

Intervention	N		Age		BMI ($kg \cdot m^{-2}$)	
	Male	**Female**	**Male**	**Female**	**Male**	**Female**
All	20	20	26.5 ± 9.6	24.3 ± 5.6	24.5 ± 2.6	23.0 ± 1.8
Rest	10	10	28.4 ± 11.4	25.9 ± 7.4	25.1 ± 2.4	23.2 ± 1.9
Exercise	10	10	26.6 ± 9.4	22.6 ± 1.3	24.8 ± 2.8	22.7 ± 1.8

All values expressed as mean ± standard deviation.

Resting Data

Glycemic Response

CeraSport (200 kcals, C-ISOC) produced a greater glycemic response than glucose (G), Gatorade, and isovolumetric CeraSport (141 kcals, C-ISOV) at 20 min (Figure 1). C-ISOC produced a greater glycemic response than Gatorade and C-ISOV at the 40, 60, and 80-min reading.

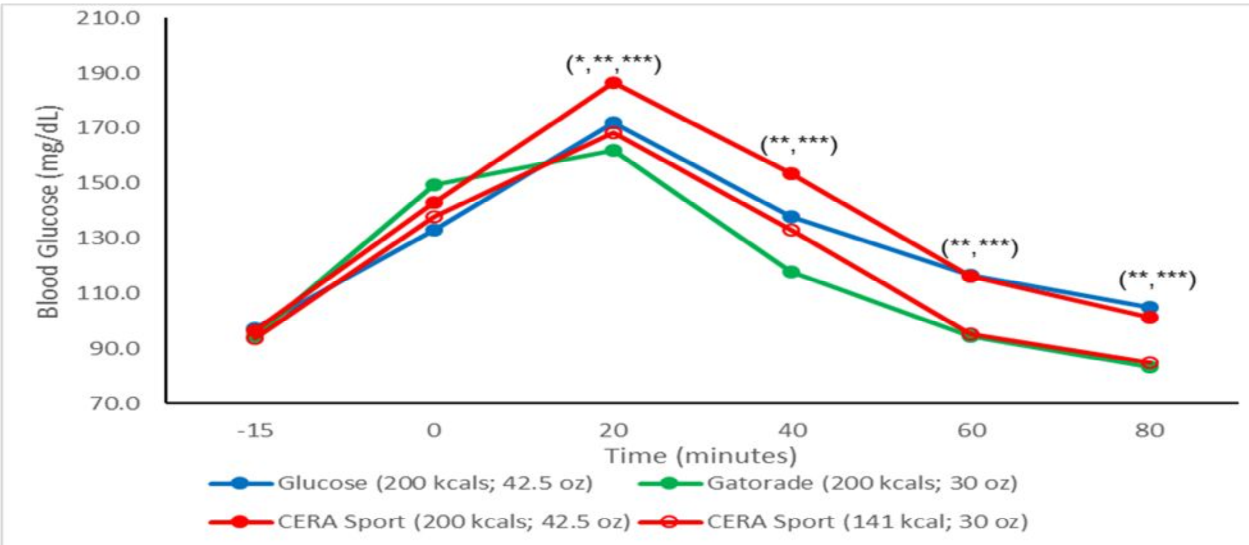

Figure 1. Blood Glucose Concentration Prior to (-15) and Following Ingestion of CHO-Electrolyte Solutions. *significant difference CeraSport (200 kcals) vs. Glucose (200 kcals); **significant difference CeraSport (200 kcals) vs. Gatorade (200 kcals); ***significant difference CeraSport (200 kcals) vs. CeraSport (141 kcals) ($P<0.05$)

Lactate Response

Blood lactate increased in all four trials (Figure 2) with a significant main effect of time. No treatment effect or interactive effect was found.

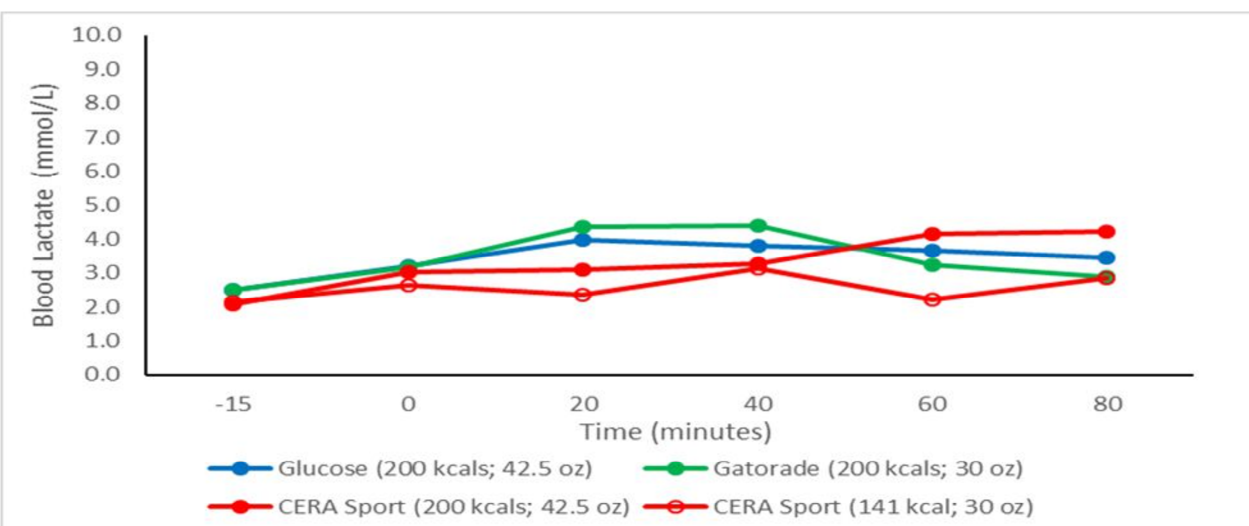

Figure 2. Blood Glucose Concentration Prior to (-15) and Following Ingestion of CHO-Electrolyte Solutions. *Blood lactate values of all trials significantly greater than baseline ($P<0.05$)

Exercise Data

Glycemic Response

C-ISOC produced greater glycemic response than G and Gatorade at 30 and 45 min (Figure 3). C-ISOC produced a greater glycemic response than Gatorade and C-ISOV at the 60 min reading.

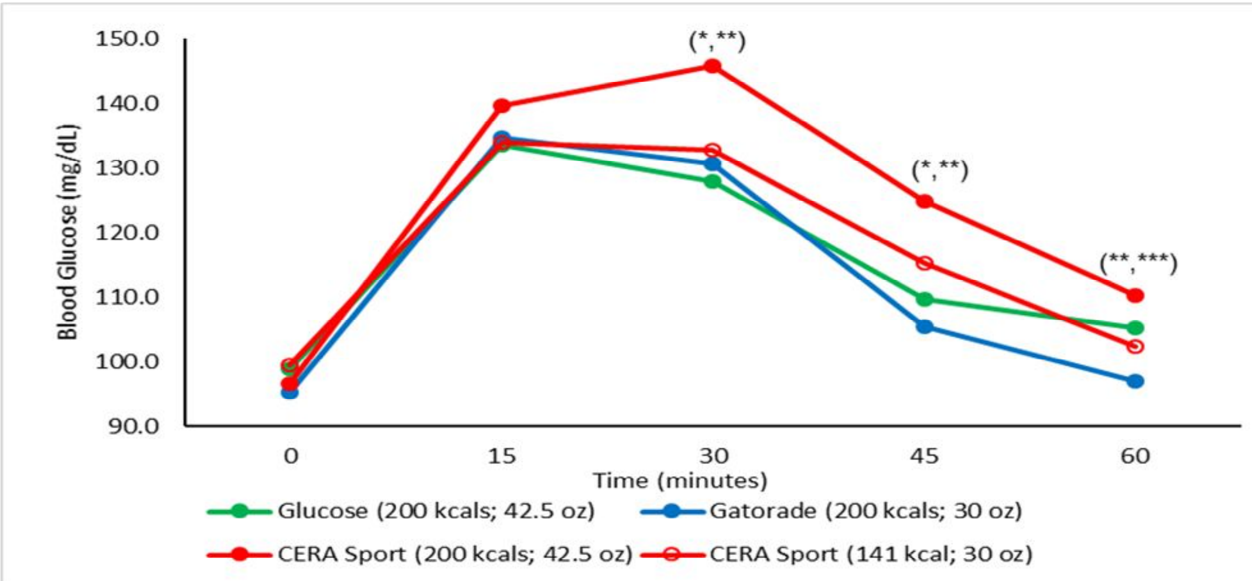

Figure 3. Blood Glucose Concentration Following Ingestion (0) of CHO-Electrolyte Solutions. See Figure 1 for explanation of symbols.

Lactate Response

Blood lactate increased in all four trials (Figure 4) with a significant main effect of time. No treatment effect or interactive effect was found.

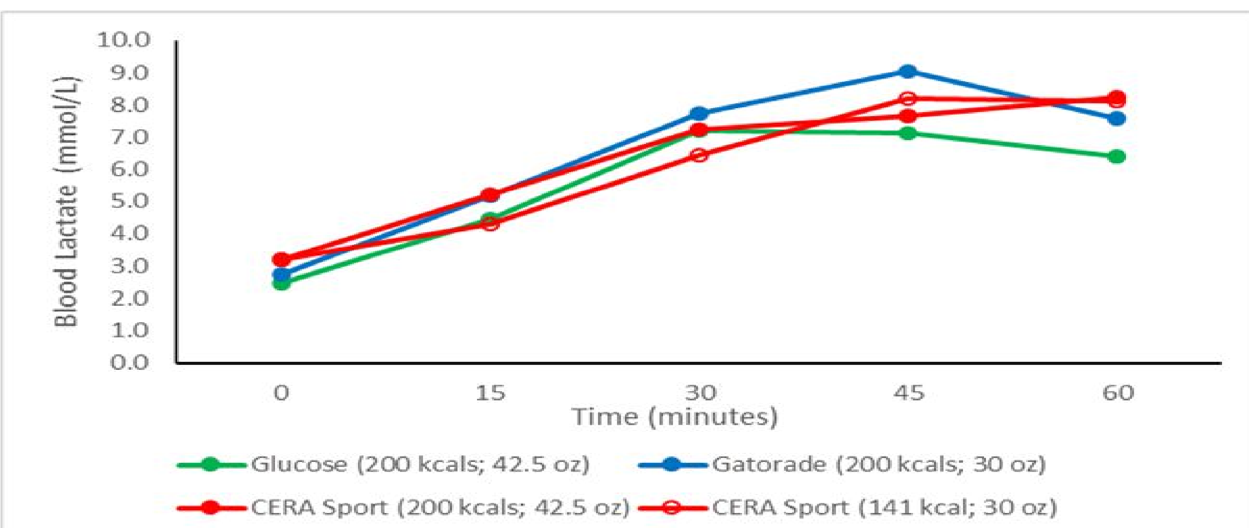

Figure 4. Blood Glucose Concentration Prior to (0) and Following Ingestion of CHO-Electrolyte Solutions. *Blood lactate values of all trials significantly greater than baseline ($P<0.05$).

Peak Values

Peak blood glucose, lactate, and urine volume at rest and during exercise are reported in Table 3. During exercise, peak blood glucose in the C-ISOC trial was 152 ± 19.3 mg·dL^{-1}, which was greater than all other treatments. C-ISOC produced significantly greater urine volume 631 ± 199 mL at rest compared to Gatorade (486.8 ± 194.1 mL). Following exercise, C-ISOC produced significantly greater urine volume (436.3 ± 178.9 mL) than Gatorade (295 ± 160.1 mL) and C-ISOV (317.5 ± 143.8 mL).

Table 3. Peak Values at Rest and Exercise.

Beverage	Rest			Exercise		
	BG (mg·dL^{-1})	**BL** (mmoL·L^{-1})	**UV** (mL)	**BG** (mg·dL^{-1})	**BL** (mmoL·L^{-1})	**UV** (mL)
Glucose (G)	172 ± 24	5.9 ± 2.4	690 ± 225	142 ± 15	9.1 ± 3.2	419 ± 181
Gatorade	171 ± 35	5.3 ± 2.8	487 ± 194	140 ± 18	11.2 ± 3.7	295 ± 160
C-ISOC	187 ± 25	6.3 ± 4.3	631 ± 199**	152 ± 19*,**,***	11.2 ± 4.2	436 ± 179**,***
C-ISOV	172 ± 19	4.0 ± 1.6	498 ± 243	139 ± 10	10.5 ± 3.8	318 ± 144

C-ISOC = CeraSport (200 kcal); **C-ISOV** = CeraSport (141 kcal); **BG** = blood glucose; **BL** = blood lactate; **UV** = urine volume; **mg·dL^{-1}** = milligrams per deciliter; **mmoL·L^{-1}** = millimoles per liter; **mL** = milliliters; All values expressed as mean ± standard deviation. See Figure 1 for explanation of symbols.

Fluid Balance

Fluid intake, recovery, and balance are reported in Table 4. At rest, C-ISOC resulted in a significantly greater fluid balance than Gatorade and C-ISOV. During exercise, C-ISOC resulted in a significantly greater fluid balance than C-ISOV.

Table 4. Fluid Balance at Rest and Exercise (mL).

Beverage	Rest			Exercise		
	Intake	**Recovery**	**Balance**	**Intake**	**Recovery**	**Balance**
Glucose (G)	1250	690 ± 225	560 ± 225	1250	419 ± 181	831 ± 181
Gatorade	882	487 ± 194	395 ± 194	882	295 ± 160	587 ± 160
C-ISOC	1250	631 ± 199	619 ± 199**,***	1250	436 ± 179	814 ± 179***
C-ISOV	882	498 ± 243	384 ± 243	882	318 ± 144	564 ± 144

C-ISOC = CeraSport (200 kcals); **C-ISOV** = CeraSport (141 kcals); **mL** = milliliters; **kcals** = Calories; See Figure 1 for explanation of symbols.

DISCUSSION

The purpose of this investigation was to summarize and contrast the availability of glucose following consumption of a glucose solution, a commercially available electrolyte drink (Gatorade), and a rice-based sports drink (CeraSport) at rest and during moderate exercise. To maximize glycemic responses, subjects were studied following a 12-hr overnight fast both at rest and during 60 min of moderate intensity exercise. Our findings indicate that the greater glycemic response of CeraSport at rest and during exercise suggest an enhanced absorption compared to solutions containing sucrose and surprisingly to glucose as well.

As expected, blood glucose increased significantly within 15 to 20 min of ingesting 50 g of carbohydrate (Figures 1 and 2). Ingestion of the isocaloric solution of CeraSport (C-ISOC) resulted in greater blood glucose values at rest (Figure 1) and during exercise (Figure 2) as well as peak values at rest and during exercise (Table 3). In addition the glycemic response (Figure 1) and peak blood glucose (Table 3) were the same with an isovolumetric solution of CeraSport (C-ISOV), containing only 35.3 gm of carbohydrate (Table 1), when compared to Gatorade of glucose (G) solutions containing 50 g of carbohydrate. These later results are consistent with a greater glycemic response of C-ISOC, which indicates a greater absorption of CeraSport.

Our results conflict somewhat with the results of Murray et al. (26). They reported that gastric emptying was generally lower at rest with 6% solutions of glucose or maltodextrin when compared to water or a 6% sucrose solution. The glycemic responses of these solutions were not reported by Murray and colleagues (26). Maltodextrin and brown-rice syrup have some similarities in that brown-rice syrup contains 5 to 20% dextrins, however the majority of the carbohydrate content in CeraSport is maltose and to a lesser extent maltotriose. Recently, Moore and O'Hara (25) suggested that absorption lower in the small intestine, specifically the jejunum and ileum, were mechanisms of action for the absorption of dextrins, which may enhance the surface are for total carbohydrate absorption. In addition, brown-syrup solutions abate cholera symptoms such as diarrhea (4,13,14,17,20,24,28,31,46) that also suggest enhanced absorption of brown-rice syrup based oral rehydration solutions (ORS).

It may also be argued that differences in osmolarity and osmolality may have played a role in the absorption of carbohydrate and thus, the glycemic response. In the present study, osmolarity differed among the solutions from an estimated 145 to 239 mOsm (Table 1). The osmolality reported by Murray et al. was 53, 184, and 349 for maltodextrin, glucose, and sucrose, respectively (26). These authors indicated no effect of osmolality on gastric emptying. Therefore, while the mechanisms are unknown in the present study, the results indicate a higher glycemic response that suggests a greater absorption of the carbohydrate source found in CeraSport. It is unknown whether this enhanced absorption would benefit exercise performance at present.

Recently, Azevedo and colleagues (2) reported an improvement in high-intensity exercise when athletes consumed a sports drink (Cytomax) containing both fructose and lactate. They authors reported a higher oxidation rate of lactate related to its availability. In the present study, we measured the blood lactate responses at rest and during exercise (Figures 2 and 4). To our knowledge, blood lactate responses have not been measured during oral glucose tolerance tests (OGTT) or following the consumption of sports drinks. Differences in blood lactate responses may have provided some indication as to routes of glucose disposal via direct and indirect pathways (5).

At rest and during exercise (Figures 2 and 4), blood lactate increased over time, and blood lactate values were considerably higher during exercise (Figure 4) than at rest (Figure 2). At rest, peak blood lactate values exceeded 4 mmoL in all trials, suggesting metabolism of glucose to lactate in disposing of the ingested glucose. This finding is consistent with the lactate shuttle and glucose paradox proposed by Brooks et al. (5). Although not significant ($P=0.08$), the C-ISOC trial generated the greatest peak blood lactate at rest (Table 3), which is consistent with the higher blood glucose values (Figure 1). During exercise peak blood lactate exceeded 9 mmoL in all trials. This result, coupled with lower blood glucose values compared to rest, suggests enhanced metabolism of ingested glucose during exercise. However, it may also be argued that the intensity of exercise exceeded our proposed moderate exercise level. We used healthy male and female subjects with a mean age of ~25 yrs who had a BMI less than 25 (Table 2). None of the subjects had difficulty completing the 60 min of exercise, and given the rise in blood lactate at rest and the rise in blood glucose during exercise, it is likely that the higher than expected blood lactate values were a result of rapid carbohydrate absorption and enhanced muscle activation in the fasted state. Results of the present study offer little insight into the differences in direct and indirect pathways as a function of sports drinks differing in carbohydrate composition.

The subjects ingested 1250 mL of fluid in both the C-ISOC and G trials, which produced more than 600 mL of urine by the end of the OGTT (Table 3). Urine volume was also higher than either the C-ISOV or Gatorade trials, likely as a result of differences in fluid ingested (882 mL). The present study did not utilize gastric emptying techniques to directly assess fluid absorption. However, our results indicate that fluid balance was greatest at rest in the C-ISOC trials (Table 4). Several studies examining ORS's concluded that brown-rice solutions decrease stool output and reduce symptoms of diarrhea when compared to World Health Organization (WHO) ORS's containing primarily glucose (4,13,14,17,20,24,28,31,45). Sarker et al. (32) and Thillainayagam et al. (38) concluded that the decreased diarrhea was indicative of an increased fluid absorption that was attributed to the reduced osmolarity in ORS's made from brown-rice syrup.

Dehydration resulting from an acute bout of exercise is often inferred from acute changes in body mass (12). Previously, Dunford et al. (12) reported that the loss in body mass was less with CeraSport when compared to water during intense military training in a hyperthermic environment. In the present study, body mass was unchanged by exercise (data not reported). This was not unexpected given the fact that the subjects exercised for just 60 min in a room temperature of ~23º C, and they had consumed between 0.8 and 1.2 kg of fluid. We found that, as with rest, fluid balance was greater in the C-ISOC trial when compared to C-ISOV (Table 4), which is likely explained by the greater volume of fluid ingested. Other than a higher net fluid balance resulting from an increased fluid intake, given the exercise duration and environment, the present results do not indicate evidence of enhanced fluid absorption or more effective rehydration during exercise.

CONCLUSION

Collectively, our results indicate that CeraSport yielded higher blood glucose values at rest and during exercise in healthy adult subjects following an overnight fast, which suggest that CeraSport may be more effective in energy absorption when compared to isocaloric solutions containing glucose or sucrose. Future studies may provide insight into comparative effects of sports drinks on hydration, thermal regulation, and performance.

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