



Influence of the Glycemic Index of Pre-exercise Meals in Sports Performance: A Systematic Review

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Received November 7, 2018; **Accepted** December 13, 2018; **Online Published** December 27, 2018

Abstract

Introduction: Carbohydrate (CHO) is essential for physical exercise. Some strategies for improving performance are based on the manipulation of the glycemic index (GI) of this nutrient during pre-exercise. Although several studies have been conducted on this subject, the use of low or high GI in a pre-exercise meal to improve performance remains undefined.

Methods: In the present systematic review, the Pubmed (Medline) and Virtual Health Library databases were searched for randomized clinical trials conducted with healthy, physically active adults between 2006 and 2019, in which performance in addition to blood biochemical parameters, substrate utilization, body composition, perception of effort, and gastrointestinal symptoms were evaluated. The identified articles were independently and blindly evaluated by two authors, and any disagreements were resolved by a third investigator.

Results: Five of the sixteen studies reviewed found differences in performance; of these, four were with low GI intervention. Few studies showed modifications in blood lactate and glucose levels beyond fatty free acid oxidation. No differences could be seen in the other parameters. The results as well as the methodologies used were heterogeneous; therefore, there are no clear advantages in determining the specific GI of the pre-exercise meal.

Conclusions: There is no evidence that the pre-exercise meal GI influences performance. The heterogeneity of the studies precludes further conclusions.

Keywords: Glycemic index, Exercise, Athletic Performance

Citation: Ferrugem LC, Martini GL, de Souza CG. Influence of the glycemic index of pre-exercise meals in sports performance: a systematic review. Int J Med Rev. 2018;5(4):151-158. doi:10.29252/IJMR-050405.

Introduction

The carbohydrate (CHO) is an essential nutrient for physical exercise because of its versatile substrate role in muscle work. In addition to maintaining glycemia and the energy supply to the brain, it is capable of contributing to exercises of various intensities due to its use in anaerobic and aerobic passages.¹ Because of this, different amounts and types of CHOs are required to achieve different effects during exercise.^{2,3}

Some strategies for improving sports performance are based on the characteristics of CHO and its glycemic index (GI), which have been extensively studied in order to investigate what influence they may have, especially in the pre-exercise meal. Previous studies have shown that the course of plasma glucose and insulin levels, following the ingestion of low GI CHO, favors the increase of free fatty acids (FFA), fat oxidation, and blood glucose homeostasis during exercise.⁴⁻⁶ In contrast, high GI meals in pre-exercise seem to decrease fat oxidation

and increase the release of hormones that stimulate glycogen breakdown.⁷⁻⁹ Decreased muscle glycogen levels are associated with fatigue and reduced intensity of sustained exercise, and thus impair factors that influence performance, such as stimulation, the perception of fatigue, motor ability, and concentration. This fact instigates the constant concern with the adequate supply of CHO, fundamental to maintaining its ergogenic effect, necessary in all sports activities at all levels, but mostly in those of high intensity and long duration.^{1,10,11} However, the results of the studies in relation to the sports performance still remain disparate.

Despite the aforementioned biochemical assumptions, studies comparing the effect of pre-exercise meals with low GI vs. high GI content on exercise performance have produced conflicting results, and several critics have reported that the evidence is inconclusive.^{12,13} Therefore, this study aimed to evaluate the impact of pre-exercise meal GI on performance

improvement in healthy individuals through a systematic review.

Methods

The current systematic review was performed using a pre-determined protocol established according to the recommendations of the Cochrane Handbook,¹⁴ and the results were presented according to the criteria of the Preferred Reporting Items for Systematic Reviews and Meta-Analyses (PRISMA Statement).¹⁵ Randomized clinical trials (RCTs) published in English from 2006 that investigated the possible effects of a meal's GI on exercise performance in adults of both sexes were reviewed, and it was determined that interventions were always carried out on physically active and healthy individuals. In January 2019, a search of the Medline (via PubMed) and Virtual Health Library (VHL) electronic databases was performed for the descriptors "Glycemic Index and Exercise" and "Glycemic Index and Sports" in research titles or abstracts. Biochemical, physical, and clinical parameters evaluated in each study's participants were considered as outcomes of interest as long as they were associated with performance (time to complete the exercise, traveled distance, or exercise to exhaustion) and the pre-exercise meal was offered 30 minutes to 4 hours before exercise was begun. No evaluations and/or changes in participants prior to physical exercise were considered as outcomes of interest. Similarly, performed and unpublished studies, abstracts of scientific events (published or unpublished), dissertations, and these were not included. The identified articles were independently and blindly evaluated by two authors of the present manuscript (LCF and GLM), and any disagreement regarding the inclusion of a study was resolved by a third investigator (CGS).

Results

Using the aforementioned descriptors and filters, 16 articles were selected as shown in the flowchart depicted in Figure 1.

The impact factor of the selected publications ranged from 1.11 to 3.76, and a large number of them was above 2.0 (46%). The year of publication ranged from 2006 to 2019, with most studies published in 2009, and the sample mean was 9.8 ± 3.6 individuals. The interventions were low and/or high GI meals, and the amount of CHO ranged from 1 g to 10 g/kg of body weight, with most studies using 1-2 g CHO/kg, ingested between 45 minutes and 4 hours before exercise. The physical modalities studied were cycling (50%), running (25%), and soccer simulation (25%). The results, grouped according to their main outcomes, are summarized in Table 1. The differences between all the intervention groups (high GI, low GI, and control/placebo) are described in the table; however, only the differences between high and low GI are described in the following items.

Performance

The performance evaluations of the studies included in this review adopted the variables time to complete the exercise, time to exhaustion, distance, power or number of sprints, in

75.2 ± 8.1 minutes, $P < 0.05$).

In the four studies that obtained advantageous results regarding performance in the low GI group, the amount of CHO used was between 1-2.5 g/kg of weight.^{16,17,19,20} These effects were obtained by consuming mostly planned meals with low GI foods, such as bran and cereal flakes, skimmed and semi-skimmed milk, apple, peach, apple juice and water, from 45 minutes to 3 hours before exercise.

In the study that found performance advantages in the high GI group,¹⁸ it was verified that the amount of CHO used was of 1.5 g/kg, being a planned meal with high GI foods, such as potato, tomato sauce, white bread, processed cheese, and watermelon.

Biochemical Parameters

All 16 selected studies evaluated one of the following biochemical parameters: glycemia, insulinemia, glycerol, FFA, triglycerides (TG), hemoglobin (Hb), hematocrit (Ht), LACTATE, cortisol, sodium, potassium, osmolarity, interleukins (ILs), TNF-alpha (TNF- α), β -hydroxybutyrate (BHB), or blood β -endorphin before, during, or after exercise.

Glycemia was the only parameter evaluated in all the

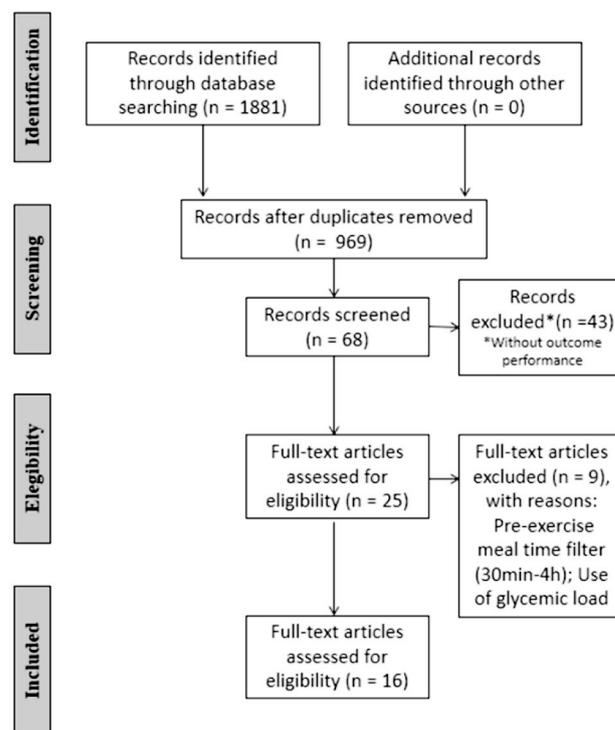


Figure 1. Flowchart of Studies Selection.

order to measure this parameter. However, only five found significant results.¹⁶⁻²⁰

Two studies measured time to complete the test^{17,19} and the use of low GI-favored performance in these studies (high x low GI: 95.6 ± 6.0 minutes x 92.5 ± 5.2 minutes; 96 ± 7 minutes x 93 ± 8 minutes; 31.08 ± 6.27 minutes x 30.05 ± 4.7 minutes., $P < 0.05$, respectively). This same advantage can be observed in 2 other studies^{16,20} which evaluated time to exhaustion,

Table 1. Influence of Pre-exercise Meals Glycemic Index on Evaluated Outcomes

Authors	Type of Study and Population	Intervention	Outcomes	Conclusions
Wu & Williams (2006) ¹⁶	RCT crossed with runners of the male sex (n=8)	Low or high GI meals providing 2 g/kg of CHO, 3 hours before exercise (run to exhaustion). Trials with 7-day intervals.	Glucose, insulin, lactate, FFA, glycerol, Ht, Hb; fat oxidation and CHO; energy expenditure; RER, VO ₂ , VCO ₂ ; perceptions of effort and thirst, fullness; body mass; fatigue; performance (running time)	The low GI group obtained higher glycemia in the first 30 minutes of exercise; however, there was no difference between the two groups after the first 30 minutes of running; RER values were higher during the first 90 minutes of running in the high GI group; FFA and glycerol concentrations were significantly higher in the low GI group during all exercises, accompanied by a higher rate of fat oxidation. Fatigue was also higher in this group; The average time to exhaustion was significantly higher in the low GI group. According to protocol (walking for 2 minutes when fatigue was reported for the first time), the duration of the running exercise at this point was also significantly higher in the low GI group; In the other variables, no significant difference was found.
Moore et al (2009) ¹⁷	Blind RCT crossed with cyclists of the male sex (n=8)	Low or high GI meal, providing 1 g/kg of CHO 45 minutes before exercise (40 km in cycle ergometer. Two trials were performed with 7-day intervals.	Glucose; lactate, osmolarity; fat oxidation and CHO; RER, VO ₂ , VCO ₂ ; perception of effort; performance (time to travel 40 km).	The low GI group presented higher glycemia at the end of the exercise and also a better performance compared to the high GI group. In the other variables, no significant difference was found.
Wong et al. (2009) ¹⁸	Blind RCT crossed with physically active individuals of the male sex (n=7)	Low or high GI meals, providing 1.5 g of CHO/kg at a recovery time of 4 hours, after a constant 90-minute run, followed by running to exhaustion after the meal. Trials with 7-day intervals.	Glucose, insulin, lactate, FFA, glycerol, cortisol, Ht, Hb, sodium, potassium and osmolarity; fat oxidation and CHO; RER, VO ₂ ; perception of effort and thirst, abdominal discomfort; body mass; performance (running time)	At the time of exhaustion, plasma concentrations of FFA and glycerol were higher in the high GI group; The time to exhaustion was lower after low GI meals in the recovery period, indicating a better performance in the high GI group; In the other variables, no significant difference was found.
Moore et al. (2010) ¹⁹	Double-blind RCT crossed with cyclists of the male sex (n=10)	Low or high GI meals, providing 1 g/kg of CHO, 45 minutes before exercise (40 km of cycling). Trials with 7-day intervals.	Glucose, insulin, lactate, FFA, TG and plasma osmolarity; fat oxidation and CHO; RER; VO ₂ , VCO ₂ ; perception of effort; performance (cycling time)	RER significantly higher in the low GI group; Average time of exercise and fat oxidation was significantly lower in the low GI group; In the other variables, no significant difference was found.
Moore et al. (2013) ²⁰	Blind RCT with untrained individuals of the female sex (n=10)	Low or high GI meal providing 2.5 g/kg of CHO, 3 hours before exercise (cycling to exhaustion). Trials with 7-day intervals.	Glucose and lactate; VO ₂ ; body mass; performance (cycling time and distance).	The time of cycling to exhaustion was higher in the low GI group, the same as the lactate levels were lower during exercise; In the other variables, no significant difference was found.
Konig et al (2016) ²¹	Double-blind RCT crossed with athletes of the male sex (n=20)	Ingestion of 750 mL of beverage containing 75 g of Palatinose or Maltodextrin (approximately 10g/kg of CHO), 45 minutes before exercise (90 minutes of cycling). Trials with 7-day intervals.	Glucose, lactate; fat oxidation and CHO; energy expenditure; RER, VO ₂ , VCO ₂ ; power in the final 5 minutes of performance (cycling time).	Athletes who ingested palatinose had greater power in the final 5 minutes of exercise, in addition to higher glycemia and higher fat oxidation during the test. There was a likely benefit, from small to moderate, in the time to complete the test after the ingestion of this beverage; In the other variables, no significant difference was found.
Bennett et al (2012) ²²	Double-blind RCT and crossed with individuals of the male (n=10) and female sex (n=4), amateur soccer players.	Low or high GI meal, 2 h before (1.5 g/kg of CHO) and within 1 h after the first session of intermittent exercise (90 minutes), being provided 2 g/kg of CHO. The sessions were separated by 3 h, with 45 minutes each session. Trials with 7-day intervals.	Glucose, insulin, lactate and FFA; fat oxidation and CHO; RER, VO ₂ , VCO ₂ ; perception of effort, fullness and gastrointestinal symptoms; sprint performance	Glycemia was higher at the end of the second exercise session in the low GI group; Lactate in the blood was higher near the end of the second session of intermittent high intensity exercise in the high GI group; For the last point of time (after sprints at the end of the second exercise session) women of the high GI group presented higher levels of FFA; CHO oxidation was higher in the high GI group at the beginning of the first exercise session; In the other variables, no significant difference was found.
Wong et al (2009) ²³	RCT crossed with runners of the male sex (n=9)	Low or high GI meal or control (hypocaloric, fat and sugar free), providing 1.5 g/kg of CHO 2 hours before exercise (21 km of running). Consumption of a solution of CHO 6.6% (2 ml/kg) immediately before and during exercise. Trials with 7-day intervals.	Glucose, insulin, lactate, AGL, glycerol, Ht, Hb, sodium, potassium, osmolarity; fat oxidation and CHO; RER, VO ₂ , VCO ₂ ; perception of effort and of thirst, abdominal discomfort, fullness; loss of sweat; performance (running time)	The concentrations of glycerol were higher during exercise in the control group when compared to the high GI group and also higher at 10 km, 15 km and 21 km in the control group when compared to the low GI group; In the other variables, no significant difference was found.

Table 1. Continued

Authors	Type of Study and Population	Intervention	Outcomes	Conclusions
Hulton et al (2012) ²⁴	RCT crossed with amateur soccer players of the male sex (n=8)	Low or high GI meal providing 2 g/kg of CHO, 3.5 h before a traditional soccer game. Trials with 7-day intervals.	Glucose, insulin, lactate, FFA, glycerol, BHB; fat oxidation and CHO; perception of effort, fullness; performance in 1 km of pre-test (time)	There was no significant difference in the other variables evaluated.
Chen et al (2009) ²⁵	RCT with runners of the male sex (n=8)	Meals of low or high GI (1.5 g/kg of CHO) or control (hypocaloric, fat and sugar free), 2 hours before 21 km of running. Consumption of a solution of CHO 6.6% (2 mL/kg) immediately before and during exercise.	Glucose, insulin, cortisol, Ht, Hb, TNF- α , interleukin-2 (IL-2) and interleukin-6 (IL-6); fat oxidation and CHO; performance (running time)	Levels of IL-6 and cortisol increased after exercise in all three groups; The levels of IL-2 decreased in control; In the other variables, no significant difference was found.
Kern et al (2007) ²⁶	Blind RCT crossed with cyclists of the male (n=4) and female sex (n=4)	Moderate or high GI meal providing 1 g/kg of CHO, 45 minutes before exercise (cycling followed by 15 minutes of performance testing). Trials with 7-day intervals.	Glucose, insulin, lactate, FFA, TG, Ht, Hb, BHB; performance (distance traveled in 15 minutes)	There was no significant difference in the variables evaluated.
Little et al (2009) ²⁷	Blind RCT crossed with athletes of the male sex (n=7)	Low or high GI meal or control (fasting), providing 2 g/kg of CHO 3 hours before exercise (90 minutes of soccer simulation, separated in two halves, with CHO reposition -0.25g/kg- in the interval of 15 minutes between the two times). Trials with 7-day intervals.	Glucose; fat oxidation and CHO; RER, VO ₂ ; perception of effort; performance (distance traveled).	RER was higher and fat oxidation was lower during exercise in the high GI group when compared to the control group. In the other variables, no significant difference was found.
Little et al (2010) ²⁸	Blind RCT crossed with athletes of the male sex (n=16)	Fasting (control) or low or high GI meal providing 1.5 g/kg of CHO 2 hours before intermittent exercise (90 minutes of soccer simulation separated in two halves). Trials with 7-day intervals.	Glucose, insulin, lactate, FFA, catecholamine; fat oxidation and CHO; RER; VO ₂ , VCO ₂ ; perception of effort, gastrointestinal symptoms; performance (distance traveled in sprints)	The levels of catecholamine were significantly higher at the end of the exercise in the high GI group when compared to the control group; Fat oxidation in the low GI group was significantly lower at the 63-70 minutes of exercise when compared to the control group, the same as fat oxidation in the high GI group was lower at 33-40 minutes when compared to control; The perception of effort was significantly lower in the low GI group when compared to control; In the other variables, no significant difference was found.
Jamurtas et al (2011) ²⁹	RCT crossed with untrained individuals of the male sex (n=8)	Fasting (control) or low or high GI meal providing 1.5 g/kg of CHO 30 minutes before exercise (cycling to exhaustion). Trials with 7-day intervals.	Glucose, insulin, lactate, Ht, Hb, beta endorphin; fat oxidation and CHO; VO ₂ , VCO ₂ ; perception of effort; performance (time to exhaustion)	Although there were some oscillations in glycemia and insulinemia between the groups during exercise, there was no significant difference in the variables evaluated at the end of the exercise. In the other variables, no significant difference was found.
Moore et al (2011) ³⁰	Blind RCT crossed with cyclists of the male sex (n=10)	Low or high GI meal, providing 8 g/kg of CHO over the 24 hours after the glycogen depletion exercise (2 hours of cycling). The next day, after 2-3 h of low or high GI meal, 40 km of cycling was performed. Trials with 7-day intervals.	Glucose, insulin, lactate, FFA TG, osmolarity; fat oxidation and CHO; energy expenditure; RER; VO ₂ , VCO ₂ ; perception of effort; performance (time)	There was no significant difference in the variables evaluated.
Brown et al (2013) ³¹	Blind RCT crossed with cyclists of the male sex (n=7)	Exercise performed to reduce glycogen, followed by a recovery period of 3 h in which there was consumption of low or high GI meal (2 g/kg of CHO), followed by a 5 km bicycle course. Trials with 7-day intervals.	Glucose, insulin, FFA and TG; fat oxidation and CHO; RER; performance (traveled time)	There was no significant difference in the variables evaluated.

RCT: randomized controlled trial; VO₂: volume of oxygen consumption; VCO₂: volume of carbon dioxide production; RER: respiratory exchange rate; FFA: free fatty acids; TG: triglycerides, Hb: hemoglobin, Ht: hematocrit; CHO: carbohydrate; GI: glycemic index; TNF- α : TNF-alpha; BHB: β -hydroxybutyrate.

and in both, the same was higher in the low GI intervention group (high x low GI: 101.4 \pm 5.2 minutes x 108.8 \pm 4.1 minutes; 48.9 \pm 10 minutes x 67.4 \pm 8.4 minutes, $P < 0.05$, respectively). In addition to these four studies, another one²¹ observed that the low GI group had greater power in the final minutes of sprinting (4.6% increase); however, the authors

affirmed that the shortest execution time of the exercise with this intervention is probable (difference of 1.03 minutes), considering the non-statistical finding. Contrary to these, another study¹⁸ evaluated time to exhaustion and observed that the duration of the test was 15% higher in the high GI group after a 4-hour recovery period (86.6 \pm 10.7 minutes vs.

selected studies, and significant differences in favor of low GI intervention were found in only four studies.^{16,17,21,22} This intervention obtained higher glycemia at different moments of physical exercise, being: the first 30 minutes of exercise, which used 2 g of CHO/kg of weight in the pre-exercise meal¹⁶; at the end of the exercise, which used 1 g and 10 g of CHO/kg in the pre-exercise meal^{17,21}; and a study²² in which the intervention was before and during a recovery period, using 1.5 and 2.0 g of CHO/kg, respectively.

Glycerol concentrations were measured in four studies,^{16,18,23,24} and 2 of them reported a significant difference during exercise or at the time of exhaustion. In one study¹⁶ the glycerol levels were significantly higher in the low GI group during exercise (20 $\mu\text{mol/L}$ x 300 $\mu\text{mol/L}$). At the time of exhaustion, one study¹⁸ showed higher glycerol levels in the high GI group (0.08 mmol/L x 0.45 mmol/L). In 10 studies, the levels of FFA were measured, and significant differences at elevated levels during exercise, at the time of exhaustion, and at the end of the exercise were found in only three of them; one of them¹⁶ observed higher concentrations of FFA in the low GI group during all exercise, another one¹⁸ obtained the same significant result at the time of exhaustion in the high GI group, and the third study,²² which applied intervention in men and women, found higher levels of FFA only in the final sprints and only in the women of the high GI group (0.1 mmol/L x 1.1 mmol/L; $P < 0.05$).

Thirteen articles analyzed lactate levels, and 2 found significant differences. These studies^{20,22} found higher lactate levels in the high GI group, but at different times: near the end of exercise in one of them,²² and during the whole exercise in another.²⁰ The intake of CHO prior to exercise in these studies was of 1.5 g/kg and 2.5 g/kg, respectively.

The inflammation parameters IL-2, IL-6, and TNF- α were measured in only one study,²⁵ which reported that IL-6 levels increased more than 100 times after exercise in all intervention groups (0.70 pg/ml x 82.09 pg/mL); however, these values returned more rapidly to baseline in the low GI meal group compared to the control alone, and did not replicate the same effects in the other 2 cytokines. The same study was the only one to find a significant difference regarding cortisol, these results being similar to those of IL-6.

In relation to the other biochemical parameters (insulin, TG, Hb, Ht, sodium, potassium, osmolarity, BHB and β -endorphin), no significant differences were found during or after sports practice with any of the interventions.

Oxidation of CHO and Fat, Respiratory Exchange Rate, Volume of Oxygen Consumption, Carbon Dioxide Output, and Energy Expenditure

The oxidation of CHO and fats was measured in 14 studies, and four found significant differences.^{16,17,21,22} Fat oxidation was higher in the low GI group in 2 studies^{16,21} (low GI x high GI: 24.9 ± 2.8 g x 10.5 ± 1.3 g and the other one without numerical data) which used 2 g and 10 g of CHO/kg of weight, respectively. Moreover, fat oxidation was lower in the low GI group,¹⁹ which used 1 g of CHO/kg of weight. In contrast, another study²² found greater CHO oxidation in the high GI group and no significant difference between the groups in

fat oxidation; the meals offered contained 1.5 g CHO/kg of weight. The respiratory exchange ratio (RER) was measured in 11 studies, and a difference was found in two of them.^{16,17} One of these studies¹⁹ found a higher RER value in the low GI group (0.94 ± 0.03 x 0.90 ± 0.03). The other study¹⁶ found the same result for the high GI group (0.98 ± 0.01 x 0.94 ± 0.01) during exercise.

The volume of oxygen consumption (VO_2) was evaluated in 12 studies, but none found differences between the groups. The production of carbon dioxide (VCO_2) was analyzed in nine studies and the energy expenditure in three. Likewise, none of them found significant differences in these parameters.

Body Composition (Body Mass and Fat)

A total of three articles^{16,18,20} looked for changes in the body composition of the participants of each research; however, none found significant differences.

Perception of Effort, Thirst and/or Appetite, Abdominal Discomfort, Fullness, Gastrointestinal Symptoms

The perception of effort was evaluated in 11 articles, and three of them^{16,18,23} also evaluated thirst. No significant results were found. Likewise, gastrointestinal symptoms and/or abdominal discomfort and/or fullness were analyzed in five studies^{16,18,22-24} and no significant results were found in any of them.

Discussion

Less than half of the studies evaluated showed differences in relation to sports performance using pre-exercise meals of high or low GI, and low GI interventions were more advantageous on this outcome. Only one study¹⁸ found a better performance after a high GI meal intake, in which the protocol used was a constant run of 90 minutes followed by a recovery time of 4 hours, then running to exhaustion. In this case, a glycogen depletion protocol was applied in which the intervention (1.5 g CHO/kg of body weight) was performed at the time of recovery between the two exercises, where the use of high GI CHO could theoretically accelerate the resynthesis of glycogen.³² The other four studies^{16,17,19,20} observed better performances after consumption of a low GI pre-exercise meal, and the type of exercise performed was predominantly cycling. In these studies, the authors believed that the improvement in performance was due to a more stable glycemic response promoted by the low GI meal, preserving glycogen for muscle work.

Although all studies evaluated and compared blood glucose levels between intervention groups, of the 4 studies^{16,17,21,22} that found a significant difference in this parameter, only two^{16,17} observed improvement in performance. These four studies verified a higher glycemia in the low GI group at the initial¹⁶ or final^{17,21,22} moments of exercise. Despite this, the increase in glycemia did not promote a significant increase in insulinemia between groups. This result was already expected, once the levels of insulin did not rise during exercise, even with CHO reposition.^{16,33-35}

The levels of glycerol and FFA presented contradictory results in studies that found differences in these

parameters.^{16,18,22} In theory, low GI meals promote a gradual release of glucose into the bloodstream and do not stimulate significant increases in insulinemia, optimizing the release and oxidation of lipids.⁹ However, only one¹⁶ of the 16 studies included in this review fully corroborated this inference, not allowing further conclusions.

Regarding lactate levels, it was possible to observe increased values after a high GI meal during or at the end of exercise in only two^{20,22} of the 13 studies that evaluated this variable. Muscle acidosis through lactate production has long been considered one of the main limiting physiological events of sports performance.³⁶ However, some findings have contributed to the change in the lactate paradigm, especially regarding its relation to intramuscular acidosis, indicating that acidosis associated with exercise is induced by the increase in H⁺ ions derived from the hydrolysis of ATP (ATP + H₂O ⇌ ADP + Pi + H⁺) and not the lactate itself. It is proposed that the lactate produced during exercise acts as a regulator of the accumulation of H⁺ ions in the intramuscular space, because it is easily transported to the interstitial space or to the blood, captured by other cells, and metabolized in the Krebs cycle or in the gluconeogenic pathway.³⁷ Thus, the results found on the effects of GI in the pre-exercise meal on lactate levels seem irrelevant.

Most of the studies evaluated presented mixed and contradictory results in relation to the variables measured, and several of them did not report any change after GI manipulation to insulin, TG, Hb, Ht, sodium, potassium, osmolarity, BHB, β-endorphin, VO₂, VCO₂, inflammatory parameters, cortisol, energy expenditure, body composition, perception of effort, thirst or appetite and gastrointestinal symptoms. Regardless of this, psychological and individual tolerance issues can also influence performance, although they are not within the scope of this review.

The number of studies that found some difference in performance remains very low compared to the total number of works evaluated. It is important to note that the heterogeneity of the results related to sports performance may be due to differences in the protocol of CHO use or the type, duration, and intensity of the exercises performed in them. Nevertheless, it can be seen that the amount of CHO consumed in most of the studies corroborates the recent

recommendation of the American College of Sports Medicine¹ that suggests the intake of 1-4 g of CHO in the pre-exercise meal. **Figure 2** illustrates the heterogeneity of the findings in relation to the parameters that presented a statistically significant difference between the intervention groups.

The following limitations of the studies in this review can be noted: (a) variations in the time interval between the meal and the exercise (45 minutes and 3 hours); (b) the difference in physical fitness of the evaluated individuals (physically active individuals x professional athletes); (c) the heterogeneity of the protocols of exercise; and (d) the reduced sample size in each clinical trial. Most of the studies evaluated GI against an acute intervention (1 meal), which may be limiting to produce more pronounced effects on performance. Likewise, the time of application and monitoring of dietary interventions was extremely short for a consistent analysis of the intervention. In this sense, a recent meta-analysis³⁸ found limitations in the results evaluated, such as the low number of studies with a test protocol for each exercise; the lack of statistical power in the studies in relation to the time of the pre-exercise meal, glycemic load, and meal composition; and the physical conditions of the participants, limiting the ability to evaluate the influence of these factors on the results of the studies. Another important point to be remarked is that the applicability of the meals in the studies evaluated in this review does not necessarily reflect the reality of the feeding of high-level athletes.

Conclusions

Judging from the wide range of controversial results or non-existent differences in the currently available literature and considering the other limitations previously described, the GI of the pre-exercise meal does not seem to influence sports performance.

Authors' Contributions

LCF and GLM were involved in the database search, extracting data, the early drafting and the revision of the manuscript; CGS acted as advisor in all stages of the research, contributed to the conception and design of the study, and aided in writing and revising the manuscript.

	Wu & Williams (2009) ¹⁶	Moore et al. (2009) ¹⁴	Wong et al. (2009) ¹⁸	Moore et al. (2010) ²²	Moore et al. (2013) ¹⁷	
Low GI	Blood Glucose	↑	↑			
	FFA and glycerol	↑				
	Fat Oxidation	↑			↓	
	RER				↑	
	Lactate					↓
	Performance improvement	YES	YES		YES	YES
High GI	Blood Glucose					
	FFA and glycerol			↑		
	Fat Oxidation					
	RER	↑				
	Lactate					
	Performance improvement			YES		

Figure 2. Relevant Findings on Performance Improvement Related to the Intervention Groups

Conflict of Interest Disclosures

The authors declare that the present work has no conflicts of interest and did not receive any type of financing.

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