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Laboratory Exercises

Understanding the Glycemic Index and Glycemic Load and Their Practical Applications*

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We have introduced the study of synthesis pathways using two experiments: 1—the determination of the glycemic index (GI) of some foods and the effects of fiber and fat on the GI; 2—the determination of blood glucose levels after the ingestion of meals with high and low glycemic loads (GL). After a practice assembly, when the foods and meals that were eaten by the students were tallied, the students were divided into groups. At the next class, three members of each group, who had fasted for 8 hr, ingested 50 g of carbohydrate in food or a meal. After ingestion, the blood glucose was measured with a portable device every 30 min for a period of 2 hr. Discussion of the data obtained in experiment 1 allowed the students to understand the mechanism of action of insulin and to understand how the GI, as presented in the literature, is determined. The students also concluded that the addition of fiber to food reduces the glycemic response even with high GI foods, and these results could be a useful strategy for diet prescription. Discussion of experiment 2 allowed the students to understand that the amount of food intake is a determining factor for the glycemic response and subsequent release of insulin. These experimental observations allowed the students to transfer theoretical knowledge to their daily lives very easily. The students approved the classes and felt encouraged to study the synthesis pathways and metabolic integration in the fed state.

Keywords: Glycemic index, glycemic load, metabolic integration, synthesis pathways.

Biochemistry is part of the physical education and nutrition curricula. One of the goals of the biochemistry course is to lead to an understanding of the pathways that produce energy and synthesize reserves, as well as the metabolic integration in both fasting and fed states.

Concepts such as the glycemic index (GI) arouse great interest in students due to the immediate application of this knowledge in their daily lives, in relation to their dietary prescriptions and the use of sports-based carbohydrates supplements before, during and after practicing physical activities.

The glycemic index (GI) is a measure of the rate at which carbohydrate changes the glycemic response and subsequent insulin release [1]. Thus, carbohydrates are classified not only by their structure (simple or complex), but also, by the physiological responses that they trigger, contributing to the understanding of insulin signaling pathways.

The GI of a food is determined by calculating the area under the curve obtained by measuring the blood glucose levels for a period of 2 hr after the ingestion of 50 g of carbohydrate of a particular food. This area is compared to the area under the curve of a standard food, usually glucose [2]. The GI of a food is expressed as a percentage of the area under the glucose curve. The GI index classifies foods as having a high (greater than 70), moderate (55–70), low (40–54) or very low GI (below 39). It is important to note that the GI can be influenced by several factors, such as the type of sugar (fructose, glucose, sucrose, etc.), the type of starch (amylose, amylopectin), how they are cooked or processed, and the presence of other nutrients such as proteins, fiber and fat [3].

However, when we analyze the diet of an individual, it is composed of several meals throughout the day, and includes various foods eaten in different amounts. In this case, the GI is only a measure of the quality of the carbohydrate, because it does not take into account the amount of carbohydrates that are ingested. In this context, the determination of the glycemic load (GL) of the meal becomes a very interesting tool, especially for dietetic analysis.

The glycemic load (GL) represents the change in blood glucose in response to the ingestion of a certain portion of food. GL determination takes into account the

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TABLE I
Experiment development: professor questions and students answers

Experiment 1
Concept: GI is a food classification using the rate at which it alters blood glucose and insulin release.
Question 1: How can we determine the GI of foods?
Students' answers:
1. Ingest food that contain carbohydrate;
2. Measure the levels of blood glucose;
3. Graph the results and compare them.
Question for answer 1: How much carbohydrate (CHO) should be consumed?
Answer: Different values were suggested by the students. But everybody agreed that the amounts used should be the same for all of the foods. After that, we determined 50 g of available CHO (CHO–the fibers of the food) to be the amount ingested.
Question for answer 2: How long should the blood glucose be measured for? And how often?
Answer: Due to the previous studies of glycemic curves, the students proposed measuring the glucose levels every 30 minutes for a period of 2 hr.
Question for answer 3: How do we know if the change is large or small? What is our reference?
Answer: Students easily proposed the use of pure glucose as the standard, and that each food curve should be compared with the glucose curve. Thereafter, the following equation to determine the GI was presented to the students: the area under the food curve divided by the area under the glucose curve.
Question 2: Other nutrients such as fiber and fat can influence the absorption of glucose. How can we check the influence of these compounds on the GI?
Answer: the students proposed to add a food rich in fiber/fat and to determine their GI. Then to compare the results obtained, to the GI of the food ingested without the fiber/fat.
Question 3: Which precautions should be taken during the experiment to avoid possible interference in the data?
Answers: After some discussion the students came up with the following precautions: that the subjects should be in a fasting state for 8 hr, that they remain seated during the experiment, be aware to the time of measurement, always use the same device; take care with hygiene and sterility during blood collection and that they chew the food thoroughly. At this time we also decided that the food should be ingested within a maximum time of 15 min.
Experiment 2
Concept: GL = (GI × the amount of available CHO of the food portion ingested)/100.
Question: How can we check how the amount of foods with different GIs influences the post-meal blood glucose level?
Answers: After some discussion, the students suggested the intake of meals with high and low GLs controlled using foods having high and low GIs in different amounts, and the measurement of blood glucose levels and the behavior of the glycemic curve resulting from each meal be compared. At this time, it was also determined that the procedures adopted in this experiment would be the same as those determined for Experiment 1.

GI of the food and the amount of food ingested, using the following formula: (carbohydrate content of the food portion—fiber content of the food portion) × food GI/100. In the case of a meal, the sum of the glycemic loads of all the foods eaten represents the total meal glycemic load [4]. By calculating the GL of meals, nutritionists can plan menus with meals that do not increase the insulin release during the day too much, avoiding the activation of the signaling pathways for triacylglycerol synthesis.

To understand the synthesis pathways signaling, using real-world data, we discussed the concepts of glycemic index and glycemic load and their applicability with physical educators and nutritionists, in a specialization course with a focus in biochemistry, through the development and completion of two experiments:

- *Experiment 1:* Determination of the GI of some foods and check of fiber and fat influence in the blood glucose response.
- *Experiment 2:* Analysis of the blood glucose response after the ingestion of meals with high and low GLs, controlled by using different amounts of foods with different GIs.

PRACTICAL STRUCTURE AND DEVELOPMENT

It is important to note that before this practical session, students have studied the glucose tolerance curve and the molecular mechanisms of action of insulin. The development of the experiments was guided by the definitions of the GI and GL and by asking some questions to the students. Table I shows the questions, the students' answers and the sequence used in the construction of the experiment.

After the experiment was developed, with the active participation of the students, the foods and meals were defined, and the students were divided into groups to carry out the practical activities as shown in Table II.

In the next class, three members of each group who had been fasting for 8 hr ate food or a meal. After ingestion, the blood glucose level was measured using a portable device (AccuCheck Active Roche®) by the other students of the group, every 30 min, for a period of 2 hr. These practices were approved by the Ethical Committee on Human Research and the volunteers assigned a written consent.

Once the blood glucose data was obtained, the students plotted the values in a MatLab (V. 7.0) spreadsheet, and using a predetermined mathematical function, calculated the value of the glycemic index of each food and presented these values with the blood glucose curve (Note: for the calculation of GI any math program can be used).

RESULTS AND DISCUSSION

Experiment 1

Figure 1 shows the average blood glucose data measured every 30 min after the ingestion of food for a period

TABLE II
Division of the groups according to the meals and foods eaten

Experiment 1: Food (50 g of available carbohydrate)[a]	
Group 1	Standard: glucose (50 g of dextrose diluted in 300 mL of water)
Group 2	Fructose (50 g diluted in 300 mL of water)
Group 3	Maltodextrin (50 g diluted in 300 mL of water)
Group 4	Sugar cane juice (276 mL)
Group 5	Watermelon juice (625 mL)
Group 6	Watermelon juice (625 mL) with soluble fiber (30 g)
Group 7	White bread (89 g)
Group 8	White bread (89 g) with butter (10 g)
Experiment 2: Meals	
Group 9	Meal 1: Food with high GI in small amounts: 1 cream cracker; 2 g of fruit jelly; 30 mL of chocolate. Low glycemic load = 7.9.
Group 10	Meal 2: Food with high GI and high amounts: 3 cream crackers, 6 g of fruit jelly, 90 mL of chocolate. High glycemic load = 23.8
Group 11	Meal 3: Food with low GI in small amounts: 100 mL of skimmed yoghurt without sugar, 10 g of oats, 1 small apple. Low glycemic load = 7.7
Group 12	Meal 4: Food with low GI in high amounts: 300 mL of skimmed yogurt without sugar; 30 g of oats; 3 small apples. High glycemic load = 23.3

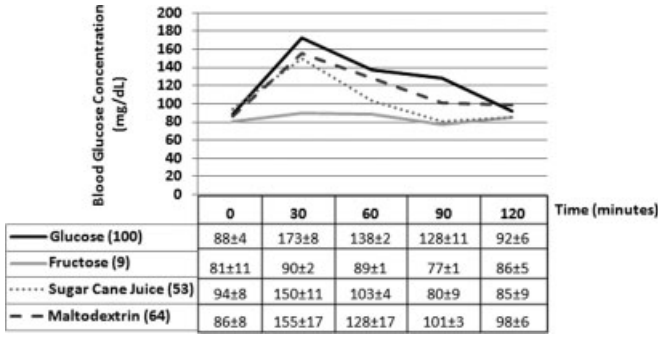
[a] The amount of food that should be eaten was determined using the table of foods composition from UNICAMP (TACO) [5] and using the international glycemic index table [6].

of 2 hr, and the GI value obtained for the groups: glucose, fructose, sugar cane juice and maltodextrin.

Taking the ingestion of 50 g of glucose to be the standard (100%), the data showed that fructose can be considered to be a low GI supplement, while maltodextrin (starch) and sugar cane juice (sucrose) have a moderate to high GI.

Figure 2 shows the average blood glucose data measured every 30 min after ingestion of the food for a period of 2 hr and the GI value obtained for the groups: watermelon juice and watermelon juice with soluble fiber (A) and bread and bread with butter (B).

The data showed that the presence of fiber or fat reduces the GI of watermelon juice and bread, respectively.



	0	30	60	90	120
Glucose (100)	88±4	173±8	138±2	128±11	92±6
Fructose (9)	81±11	90±2	89±1	77±1	86±5
Sugar Cane Juice (53)	94±8	150±11	103±4	80±9	85±9
Maltodextrin (64)	86±8	155±17	128±17	101±3	98±6

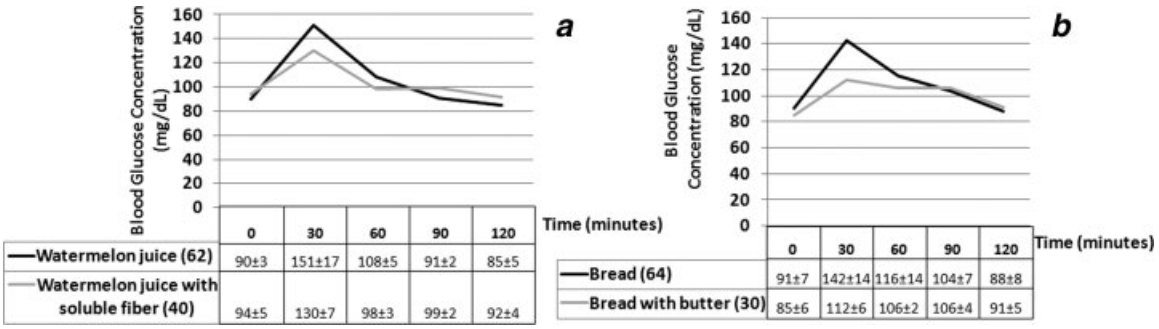
FIG. 1. **Mean (±standard deviation on the table) values of blood glucose for the groups: glucose, fructose, sugar cane juice and maltodextrin obtained every 30 min for a period of 2 hr**. The value in parentheses represents the GI determined from the area under the food curve, as compared with the area under the glucose curve.

After obtaining the graphs and the GI of different foods, the groups also had to fill an experimental report with the headings shown in Table III.

From the analysis of the data obtained in Experiment 1, the students discussed the changes in their blood glucose levels and their subsequent insulin release in response to the ingestion of foods with different glycemic indices. Another important point to be considered is that the students understood how simply is to determined the GI of foods that they see in books or on the Internet and that they could therefore take a critical posture in relation to them. Some of standardization experiments use 50 g of white bread as a standard, and this was immediately perceived by students not to be the best choice. The bread glycemic curve was lower than others foods making difficult to classify the GI. Other problem of bread as standard is the fact that the preparation can influence the amount of carbohydrate.

The influence of other nutrients such as fat and fiber in the response of the blood glucose levels was also easily seen. Bringing the discussion to daily life, the students concluded that the addition of fiber (flaxseed meal, oat flakes, flour, fruit hulls, etc.) could be a useful practice to manipulate the diet of diabetic people and/or for people who intend to lose weight.

The discussion of the students about the application of this knowledge to the intake of carbohydrates before, during and after physical activity, as a way to recover their reserves of glycogen and to provide energy for their



	0	30	60	90	120
Watermelon juice (62)	90±3	151±17	108±5	91±2	85±5
Watermelon juice with soluble fiber (40)	94±5	130±7	98±3	99±2	92±4

	0	30	60	90	120
Bread (64)	91±7	142±14	116±14	104±7	88±8
Bread with butter (30)	85±6	112±6	106±2	106±4	91±5

FIG. 2. **Mean (±standard deviation on the table) values of blood glucose for the groups: watermelon and watermelon with soluble fiber (*a*); bread and bread with butter (*b*) obtained every 30 min for a period of 2 hr**. The value in parentheses represents the IG determined from the area under the food curve as compared to the area under the glucose curve.

TABLE III
Experiment 1 report

Goals:
Methods:
Subjects:
Foods:
Blood Glucose Measurement:
Precautions taken in obtaining the data:
Collection Times:
Results:
A table to record the results and graph paper to plot the data.
Questions to guide the discussion:
1) Why is the determination of the GI of foods containing carbohydrates important?
2) What are the biological factors and/or experimental factors that may influence the determination of the GI?
3) What is the possible explanation for the differences in the behavior of the blood glucose curves between foods as shown in Figure 1?
4) What is the influence of other nutrients such as fiber and fat on the glycemic index of a food? What is the practical application of this knowledge?
5) A very common strategy taken by physically active people is to ingest carbohydrate before, during and after training or competitions. What is the purpose of this strategy at each of these moments? Based on the data, which type of carbohydrate is appropriate to use at each moment?
6) What considerations should we take into account when only using the GI of a food to analyze a meal?
Conclusions:

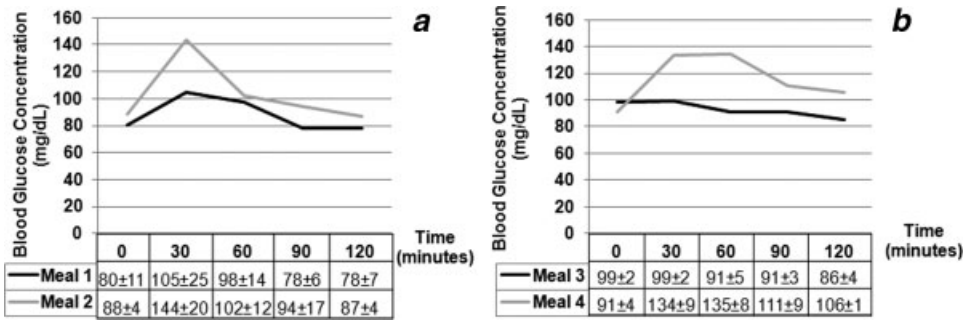


FIG. 3. **Mean (±standard deviation on the table) values of blood glucose obtained for the groups: Meal 1 (high-GI foods in small amounts) and Meal 2 (high-GI foods in high amounts) (*a*); Meal 3 (low GI foods in small amounts) and Meal 4 (low GI food in high amounts) every 30 min for a period of 2 hr (*b*).**

activities, led them to the same recommendations as proposed by the literature. That is, the intake of low GI carbohydrates is necessary before activity to avoid insulin spikes at the beginning of the activity, which could lead to hypoglycemia. During the activity, it is necessary to ingest CHO with a moderate to high GI, in order to provide energy quickly to the active muscles. After the exercise, it is important to ingest high GI CHO to release insulin and start the recovery of the glycogen reserves [7–9].

Experiment 2

Figure 3 shows the average blood glucose data measured every 30 min after the ingestion of Meals 1 and 2 (high GI foods in small and high amounts) [A] and Meals 3 and 4 (foods with low GI in small and high amounts) [B] for a period of 2 hr.

The data obtained showed that the amount of CHO in meals affected the blood glucose response as much as the GI of the foods.

For the analysis and discussion of these results, the students also had to fill out a report with the headings show in Table IV.

The analysis of Experiment 2 allowed the students to understand the concept of glycemic load and to correlate the GI of foods, the amount of food intake and the blood glucose response. The conclusions that were reached were that the amount of food eaten is a factor as important as the GI of the food in the glucose response and

TABLE IV
Experiment 2 report

Goals:
Methods:
Subjects:
Meals:
Blood Glucose measurement:
Precautions taken in obtaining the data
Collection Time:
Results:
A table to record the results and graph paper to plot the data.
Questions to guide the discussion:
1) What is the relationship between the glycemic load and glycemic index in the meals above?
2) Analyzing the behavior of blood glucose in each case, what is the probable amount of insulin release for each meal?
3) What are the practical implications of this study?
Conclusions:

the subsequent release of insulin. A meal containing foods that have a low GI, if ingested in high amounts, can change the blood glucose levels as greatly as the intake of a high GI food. Similarly, the intake of foods with high GIs in small amounts, can lead to small changes in blood glucose, as is also found in foods that have a low GI.

Applying these observations to real life, the students concluded that manipulation of the amount of food ingested, especially in weight loss diets, is the most useful because it allows the nutritionist to include foods with high GIs in small amounts on the menu and not to eliminate them entirely as fad diets propose. Moreover, nutritionists must be alert to the fact that foods cannot be eaten freely because they have a low GI. Even for these foods, the amount that is eaten is a determining factor in the glycemic response and for this reason they should also be consumed with moderation.

In a recent study, Sacks *et al*. [10] monitored a group of more than 800 overweight and obese people for 2 yr, who followed diets that differed in fat, protein and carbohydrate levels, and their relative weight loss. The authors concluded that the determining factor for weight loss was the amount of the food intake, despite the composition of the diet ingested, in terms of macronutrients.

It has been suggested that a diet with an adequate food volume composed of foods that have a low glycemic index will improve insulin sensitivity and lower plasma triacylglycerol levels, thereby reducing the risk of developing diabetes, heart disease, and helping to treat obesity [11–13].

CONCLUSIONS

In general, the students enjoyed the practical session and felt encouraged to discuss the results obtained and to compare them with the biochemical knowledge acquired up to that date. This practical session also encouraged students to study the synthesis pathways and metabolic integration in the fed state. The theoretical knowledge and experimental observations allowed the students to transfer this content easily to their daily lives. It is important to emphasize that the cost of the practical session is relatively low and is determined by the food chosen and the number of students who undertake the experiments which determine the costs of the blood glucose tests.

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